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A NEW CLINICAL TEST FOR TEMPERATURE SENSITIVITY

A CONTRIBUTION TO THE STUDY OF
TEMPERATURE REACTION IN NERVOUS DISEASES
BASED ON THE REACTION TO SIMULTANEOUS
COLD AND HOT STIMULATION

(IN TWO PARTS)

BY

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DEPARTMENTS OF PSYCHOLOGY AND NEUROLOGY
COLUMBIA UNIVERSITY
NEW YORK CITY

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
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A NEW CLINICAL TEST FOR TEMPERATURE SENSITIVITY

BASED ON THE REACTION TO COLD AND HOT STIMULI SIMULTANEOUSLY APPLIED

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GENERAL OUTLINE

Historical	Proportion of responses giving only one sensation
Experimental	Reaction to single stimuli
Statement of problem	Overlapping of reaction-time to cold and hot
Apparatus	Responses giving both sensations
Material and Method	Detailed consideration of responses to double stimuli
Subjects, Areas tested, Arrangement of Series,	Responses giving <i>hot</i> first—comparison with
Temperatures used	those giving <i>cold</i> first
Procedure	Responses giving <i>cold</i> first
Conditions affecting results	General distribution
Limitations of method	Effect of double stimulus on reaction-time
Changes in temperature of skin or stimulus	to hot
Topography of warm and cold spots	Summary of individual cases
Results	Conclusions
General character of reactions to double stimuli	
Proportion of responses giving <i>cold</i> first	

HISTORICAL

A review of the literature on the temperature senses is a task of rather large dimensions. There are so many factors, however, influencing any investigation in this field, and there is so little in the literature that bears specifically on the present problem, that I shall attempt to give a somewhat sketchy survey of the whole field.

The problems attacked have been many, the methods of approach various, and the conclusions of all possible degrees of diversity; so that it is not always easy to give a very clear presentation. Indeed, one fervently reëchoes the words of Trotter and Davies: "The study of thermal sensitivity is a peculiarly difficult one, not only in regard to technical detail, but especially in regard to obtaining clear conceptions and expounding them without confusion."¹

¹ J. f. *Psychol. u. Neurol.*, 20, 1913, p. E 106.

There seem to be four general classes of problems that have been investigated in regard to the temperature senses—four general methods of approach, which while not mutually exclusive, are sufficiently distinct to give a certain coherence to the discussion. These four classes are:

1. *The psychophysical*—under which I have classed the various problems of *sensitivity* that occupied so large a part of the earlier literature—problems of the threshold values of sensation, of discrimination, and of the limiting values where sensations of temperature pass over into those of pain; and the question of topography—the relative sensitivity of various parts of the body.

2. *The physiological*—which took its impetus from the question of the specific energies of the nerves, because of the apparent contradiction that cutaneous sensations offered to this theory. Under this class will fall the

question of the nature and distribution of the end-organs (closely allied to the topography), the question of the nature of the arousal of the sensation and the consequent explanations of adaptation, and the question of the constitution of the nerves which was raised by the recent work of Head.

3. *The psychological*—which is, to be sure, bound up with all the rest, but under which I have chosen to consider the questions related chiefly to qualities of sensation and reaction-time.

4. *The clinical*—which is, to a great extent, merely the application of results obtained by other methods to abnormal cases. It has, however, set many of the problems under the other headings, and has, besides, its peculiar problems of sensory dissociation to treat.

PSYCHOPHYSICAL INVESTIGATIONS

It is quite fitting to begin from the psychophysical point of view, since the very first recorded observations are those of Weber (24), that a metal cylinder of 15° C. felt colder on some parts of the body than on others, and similarly, one of 40° felt warmer in some places than in others. Fechner, also, did not omit to test temperature sensitivity to corroborate Weber's law; but these experiments we may pass over, to consider the more specific attempts to measure temperature sensitivity.

Threshold values may here, as in other cases, be of three sorts, although our authors have not always distinguished them very clearly. The stimulus limen (R. L.) would correspond to the least difference from the skin temperature that could be sensed; the difference limen (D. L.) would correspond to the least noticeable difference between two stimuli at other than skin temperature; the terminal limen (T. R.) would be the limiting value where sensations of temperature ceased to be felt as such. The first experiment of this sort was that of Nothnagel (16), in 1866. He used two small cylindrical vessels filled with water, each fitted with a thermometer dipping into the water. The water was heated or cooled to the desired temperature by inserting into it a large key previously heated or cooled. The two vessels were applied successively to the same spot, and the discriminative interval

determined. He made out discrimination tables for various parts of the skin surface, as a starting point for the investigation of pathological conditions, in which he was primarily interested. Discrimination, which he found to be best between 27° and 33° C., varied from .2° on the forearm, upper arm, and cheek—the most sensitive parts—to 1.2° in the middle of the back. At that time, of course, the separation of thermal sensations into two separate series had not been thought of; consequently, Nothnagel's values may be sometimes true difference thresholds and sometimes may represent the absolute threshold, or least noticeable sensation for cold or warm. After the distinction had been made, Eulenberg made an attempt to determine the least differences above and below the skin temperature that could be perceived as warm and cold respectively (7). Eulenberg's apparatus was somewhat more refined. He used two thermometers with flattened bases, one of which had its base wound with a platinum wire through which a current could be sent to raise the temperature of the base. The heat was controlled by a rheostat. One thermometer was placed on the skin and left until it registered the skin temperature; the other was then heated by the current to a point slightly above or below this and set down in the same place. Minimal differences perceived as cold and warm respectively were thus determined for various areas. The difference

R. L. FOR COLD AND WARM (Eulenberg)

	<i>Minimal Cold Difference</i>	<i>Minimal Warm Difference</i>
Sternum	.2°	.2°
Fingers—dorsal	.2— .3	.2
Ball of thumb	.3— .4	.4
Back of hand	.3— .4	.4
Forearm—dorsal	.3— .4	.2
Forearm—volar	.4	.3— .4
Cheek	.4	.4
Upper arm	.5	.5
Top of foot	.5	.5— .6
Leg—upper part	.5— .6	.5— .6
Leg—middle part	.7	.7
Thigh—ventral	.6	.5— .6
Back—lateral	.9	.9—1.0
Back—median	1.0	1.1

for each sense was found to be practically identical for the same area of the skin, and to vary, for different areas, from .2° C. in the most sensitive parts (sternum, back of fingers) to 1° or 1.1° on the back.

The third sort of threshold—the pain threshold for thermic stimuli—was first investigated by Donath, whose work was published in 1884 (6). He contrived two instruments, one for investigating cold-pain, which he designated kryalgimeter (*κρύος*—cold, *ἄλγος*—pain), the other for warm-pain, which he called thermalgimeter. The kryalgimeter was a thermometer ending in a spiral mercury vessel which fitted exactly into an opening in a piece of heavy flannel. This was placed on the skin and cooled by spraying it with ether—the flannel protecting the surrounding skin—until a sensation of pain was felt. The thermalgimeter was a similar thermometer, ending in an elongated bulb which was wound with a platinum wire through which a current could be sent. This was placed on the skin, and the temperature increased until pain was reported. He found noteworthy individual differences among his six normal subjects and wide variations, according to the part of the skin stimulated, from -11.4° to 2.8° C. for the appearance of cold-pain, and from 36.3° to 52.6° for warm-pain. In general, ventral surfaces were more sensitive than dorsal, upper extremities than lower, left side than right; the ends of the fingers were the least sensitive. He concluded that the pain aroused by extreme degrees of temperature is a much grosser sensation than that from the middle intensities, and lacks the fineness of discrimination of the latter. The values that Donath obtained for cold-pain seem extraordinarily low, and suggest that his method may have overlooked the effect of adaptation: he does not state how long the contact with the skin continued. He does, however, say that cold-pain is much more difficult to recognize and define, and arises more slowly than warm.

Neumann, in 1903, investigated the same question, in regard to the warm sense only, in order to compare the interval between the sensation of warmth and that of pain (15). He used a metal cylinder partly filled with water that could be heated by an electric cur-

rent. A thermometer was inserted into the water and attached to the handle; the handle also had a little plunger by which the water was kept constantly circulating, in order to assure an even temperature throughout. Neumann found that while the threshold for warm might vary as much as two degrees C. for the same individual in the same place at different times, the threshold for pain was fairly constant for the same place and varied according to the area stimulated from 35° to 52° —values practically identical with Donath's. Both Donath and Neumann were interested chiefly in pathological conditions, and their work will be referred to later.

The other question pertaining to sensitivity is that of the relative sensitivity of different parts of the body. Goldscheider was the first to make a systematic attempt to experiment upon this question. His earliest experiments were published in 1887 (9a). He explored the skin with a small metal surface that had been heated or cooled, and divided sensitivity into twelve degrees of intensity for cold stimulation and into eight for warm. It is clear, of course, that the actual temperature of the skin in this case is of great importance, and also the proportion of warm and cold spots in the various areas. Alrutz repeated topographical experiments after adapting each area tested to a temperature of 32° (2a). He was able to differentiate only three degrees of sensitivity; but he used a stimulus temperature of 34.5° , in order to have it below the point at which the cold nerves are paradoxically stimulated by high temperatures, while Goldscheider had used a temperature of 45° — 49° .² Such radically different modes of procedure could not, of course, arrive at the same results. The truth probably is that these differences of sensitivity are not peculiarly areal differences, but are caused by differences in skin temperature and by the presence of more or less strongly reacting spots in certain areas. Whether these spots have any constant topographical distribution is doubtful; in any case, it could only be

² The difference is more than one of method. It is due to the divergence in the views of Goldscheider and Alrutz as to the nature of the sensation of heat—the former maintaining it to be just an intensified warm, the latter a fusion of warm and paradoxical cold.

determined by a systematic exploration, point by point.

PHYSIOLOGICAL INVESTIGATIONS

It was originally supposed that the same nerves conducted all cutaneous impressions. It was not until 1883 that Blix, who was interested to determine how well-founded was the contradiction that cutaneous sensations offered to the theory of the specific energies of the nerves, discovered that sensations from various kinds of cutaneous stimuli were limited to permanent spots—among the sensations, those of cold and heat (3). The same discovery was made independently at about the same time by Goldscheider (9*b*), and by Donaldson (5). Blix used an induced current with a pin for the stimulating electrode, and found that distinctly localized spots responded by sensations of pain, pressure, cold, and heat, and that these spots were never superimposed. Other methods of stimulation confirmed the results, and it was further observed that a cold spot never responded to a warm stimulus, nor a warm spot to a cold stimulus. Blix concluded that there were separate cutaneous nerves with separate terminations in the skin. He mapped out various regions of his own body for temperature spots and found them arranged irregularly in groups, distributed fairly uniformly over the body, most closely on the dorsal side of the hand and fingers, most scattered on the sacral region of the back, with cold spots always more numerous than warm. Donaldson's observations confirmed Blix's. Goldscheider found a much more numerous count, but his method was probably at fault, since later work has corroborated Blix. The latest and most complete observations were those of Sommer (19), reported in 1900. He found (for the benefit of anybody who is statistically minded) a total of half a million cold spots and thirty thousand warm—an average of 12–13 cold spots and 1–2 warm spots per square centimeter.

Donaldson made the earliest attempt to discover the end-organs associated with the sensations of warm and cold. He made a histological examination of a piece of skin that had previously been explored and marked and then excised, but his findings were entirely

negative. He evidently did not cut deep enough, for he found that the recovering area was perfectly sensitive. Von Frey, whose work was published about ten years later, has done the most constructive work in the discovery of the nerve-endings (23). It is now generally supposed that the end-bulbs of Kraus mediate cold sensations, and the Ruffini corpuscles those of warmth.

It is generally assumed that the warm end-organs lie deeper than the cold, because of the greater difficulty in localizing warm sensations and because of their longer reaction-time. Thunberg pointed out that these assumptions were not sufficient proof; both conditions might be due to the nature of the end-organ—Goldscheider indeed had assumed that the warm end-organs had a longer latent time. Therefore Thunberg undertook an investigation of the question by an indirect method (20*b*). He applied silver plates of the same area but of varying degrees of thickness to the skin. The principle, if I understand it correctly, was as follows: Two plates of the same area and temperature, but of different thickness, will add warmth to, or withdraw it from the skin in different amounts, in a measurable proportion to the thickness. Since the skin-temperature is a balance between the temperature of the blood and the outer temperature in contact with the skin, the amount of warmth added to—or withdrawn from—the skin until the different layers of the skin reach a new temporary balance will be a measure of the depth at which the balance is attained. Consequently, the application of a very intensive stimulus of less thickness will have a greater effect on the more superficial layers than on the deeper-lying layers of the skin; while on the other hand, a stimulus of less intensity but greater thickness will give a relatively favorable opportunity for the stimulation of the deeper layers. Since then, as Thunberg found, the more intense, thinner plate provided the optimum conditions for the arousal of paradoxical cold sensations, while a stimulus of less intensity but of greater mass offered the best conditions for obtaining a strong warm sensation, he concluded that the cold nerve-endings lie more superficially, the warm nerve-endings deeper.

The question of the depth at which the end-organs lie is closely connected with the question, somewhat theoretical but nevertheless important in its practical bearing, of the nature of the arousal of thermal sensations. Does the end-organ change its temperature or does it remain constant? If it changes, do the changes take place in the same direction as the changes in the outer skin-temperature or in the opposite direction? It is generally considered that, since the skin-temperature is found to be differently tempered for changing conditions of temperature without arousing any sensation, there is a zone of indifference—usually called the “physiological zero”—which is capable of shifting up and down the scale within rather wide limits. But Thunberg points out (20c) that we have no proof that the temperature of the end-organs is actually the same that we obtain when we measure skin-temperature, or that it necessarily changes in the same direction. What we get by measuring the skin-temperature is a balance between the different layers of the skin, which are normally cooled from without by the air and warmed from within by the blood. But when the outer layers are cooled by contact with the cold, the deeper layers, according to Thunberg, have their temperature raised by an increased flow of blood to restore the balance; so a fall of temperature toward the surface takes place. Somewhere between, there may be a layer that maintains its own temperature. Since it is not known in what layer the end-organs are, it cannot be said what is the nature of the change. There are two views current: that of Weber, that temperature sensation is due to change of skin-temperature (or, as amended by Thunberg, to change in the layer of the end-organ) and lasts as long as the change lasts; and that of Hering, that temperature sensation is due to the actual temperature of the end-organ and lasts until the physiological zero reaches a new location—the temporary temperature of the end-organ. According to Hering, the shifting physiological zero—the adaptation to any actual temperature of the end-organ—is what accounts for the absence of sensation, though just what the physiological zero is is not clear. According to Weber, any relatively stable

temperature following a period of change is the cause of the absence of sensation. The difference in the two views is due partly to differences in their findings as to the duration of sensation.

An experiment to determine the duration of a sensation with a constant stimulus was made in 1903 by Holm (10). He found that the duration of the sensation decreased as the temperature of the stimulus approached that of the skin, and he thought this suggested that the duration of the sensation probably agreed with that of the temperature change, since prolongation of the stimulus did not prolong the sensation. He found no after-images with stimuli of middle intensities, but extreme cold gave rise to an after-image which appeared some moments after the removal of the stimulus—due, Holm thought, to paradoxical cold sensations occasioned by a quick warming of the cooled cold-organs by the blood. The absence of after-images he thinks is a further support of Weber's theory; because if the absolute temperature were effective, one would expect after-images with weak as well as with strong sensations.

DURATION OF SENSATION (Holm)

<i>Cold</i>	
<i>Temperature</i>	<i>Average Duration</i>
30°	31 sec.
25	47
20	72
15	112
10	165
5	210
<i>Warm</i>	
<i>Temperature</i>	<i>Average Duration</i>
40°	126 sec.
45	152

There is a recent study on the effects of adaptation by Edwina Abbot, which suggests a somewhat different conclusion (1). She made four groups of experiments for four conditions of adaptation. In the first group her subjects had their hands adapted to a temperature of 40°, by immersion in warm water. Then the D. L. was determined by dipping the two hands into separate jars, for 37.5°, 35°, 32.5°, 30°, 27.5°, 25°, 22.5°, 17.5°. She found

a "consistent drop" in the D. L. at 32.5° . In the second group, she determined the D. L. for 40° , 32.5° , 27.5° , 25° , after adaptation to various temperatures. She found that the limen for 32.5° varied hardly at all under the varying conditions of adaptation. This seemed to point to 32.5° as a condition of adaptation suitable for a norm by which to compare the limena for different temperatures under other conditions of adaptation. In the third group, to test this, she compared the D. L.'s for various temperatures after adaptation to 40° , 32.5° , 17.5° , and found that the D. L.'s for 32.5° under the three conditions of adaptation were within $.5^{\circ}$ of each other, while for other temperatures the D. L. rose after adaptation to 40° , and fell after adaptation to 17.5° . The fourth group was undertaken to test the possibility of a double adaptation—an adaptation to both extremes at once. In this group, she compared the effect on the D. L.'s for various temperatures of adaptation to 40° , with the effect of a double adaptation, to 40° immediately followed by adaptation to 17.5° . The values for the D. L. were practically alike in this experiment for extreme temperatures, but between 35° and 27.5° the D. L. was higher after double adaptation, except again, at 32.5° , where the value was about the same for both conditions. This was considered to confirm the hypothesis. All of Dr. Abbot's results suggested that varying conditions of adaptation had practically no effect on sensitivity at normal skin-temperature, and she concludes that "persistence of skin-temperature as a more or less constant basis for appreciating variation of temperature is a much more possible conception than the . . . physiological zero," "since it does not fit the facts . . . and since the facts it attempted to explain may be explained without it." Dr. Abbot's observations were not very numerous, however, and her results are suggestive rather than conclusive.

There is one other question to be considered under the physiological caption—the question of what constitutes an adequate stimulus for warm and cold spots. Blix had first used an electrical stimulus, and found both warm and cold spots sensitive. Kiesow (11) found temperature spots likewise sensitive to electrical

stimulation, and to mechanical stimulation—if the observations were carefully made, if the observer was sufficiently practised, and if conditions were otherwise favorable. That is, he obtained responses to mechanical stimulation in nine out of thirty tested cold spots, in twenty-one out of forty-six trials; in ten out of thirty trials with warm spots for one observer, five out of fifteen for another, and seven out of ten for a third. The percentage of successes is not startling, but is enough, Kiesow thinks, to prove mechanical stimulation possible. Goldscheider (9c), Alrutz (2c) and others have confirmed the possibility of mechanical stimulation, though Head (18) finds no evidence of it. The earlier investigators had found that cold spots never responded to warm stimuli, nor warm spots to cold. Kiesow tested the spots by means of the "opposite stimulus" and got a rather curious result. He never got a cold sensation by cold stimulation of a warm spot, but, on the other hand, he found scarcely a cold spot that would not respond to temperatures of 47° to 50° by a sensation of warmth. This, Titchener says, is a misreading of the facts: "In reality, radiation occurred, and the process observed was not that of warmth but of heat."³ However, paradoxical sensations of cold—*i. e.*, cold sensations from a warm stimulus applied to a cold spot—were discovered by von Frey (23), and confirmed by Thunberg (20a), Alrutz (2d), and are admitted by all. Paradoxical warm sensations have been described by Goldscheider, but no other investigator has been able to discover them.

PSYCHOLOGICAL INVESTIGATIONS

It is perhaps somewhat arbitrary to attempt to separate the psychological questions from the physiological, but I have reserved this designation for the investigations relating chiefly to the question of the nature and quality of the sensation of heat—the question that has loomed largest on the psychological horizon and that brings about a triangular debate between Thunberg, Alrutz, and Goldscheider—and for the determination of the reaction-time to cold, warm, and hot stimuli.

³ TITCHENER, 'Quantitative Instructor's Manual,' p. 86.

Paradoxical cold sensations are the crux of this discussion. While everybody admits their existence, there is considerable diversity of opinion as to the exact manner of their arousal and the interpretation of their significance. Goldscheider, who originally believed they were due to mechanical stimulation, now admits that they are truly paradoxical, but difficult to arouse except from very sensitive cold spots (9d). He says they never appear with a stimulus of less than 38° , and are not a frequent phenomenon with temperatures below 41° – 45° . Alrutz and Thunberg, however, find paradoxical cold sensations a constant phenomenon from temperatures of 36° – 38° and up (2b, 20a). Goldscheider also reports paradoxical warm sensations from cold stimuli (of 21° – 27.5°); consequently, the significance of paradoxical sensations for Goldscheider is simply as another means of confirming the specific nature of the end-organs. In addition to paradoxical cold sensations by point stimulation, Alrutz and Thunberg showed that they could be obtained also by areal stimulation with an object at a fairly high temperature, if the area was first adapted to moderate warmth for two minutes. These facts, and the absence of paradoxical warm sensations, in their observations, led these two investigators to the belief that paradoxical cold sensations were an essential element in the sensation of heat. Alrutz found two facts in his earlier work that confirmed this: first, that on areas of the skin where cold spots are lacking, stimulation by any degree of heat produces warm sensations and pain sensations, but never heat; second, that on areas where cold sensitivity was strongly developed but warm sensitivity weak, sensations of heat could be experienced but never strong warm sensations. In a later paper (2a), Alrutz added a third proof that the hot sensation involved the stimulation of cold nerves, from experiments in reaction-time of warm, hot, and paradoxical cold sensations. Alrutz found that hot sensations had a characteristic quality, which he called *Anschwellung*—a sort of crescendo effect from the first perception of warm to the full perception of hot. This meant that the reaction to warm was quicker than that to hot. The average

reaction-time for warm at a temperature of 42.5° , is 385σ ; for hot at about the same temperature, 795σ ; for warm at 43 – 44.5° , 267σ ; for hot at 43 – 46.5° , 624σ . This longer time for the perception of hot Alrutz finds to be parallel with the reaction for paradoxical cold sensation— 745σ for a stimulus of 42° , 750σ for a stimulus of 51° .

Alrutz's figures are based upon rather few observations, but he compares them with those that Goldscheider had previously obtained, and finds them quite similar. Goldscheider had found a quality in the sensations he calls warm, similar to the *Anschwellung* of Alrutz's hot sensations—that is, a gradual rise from the "minimum" to the "maximum" of intensity.

REACTION-TIME TO HOT (Goldscheider, Alrutz)
Goldscheider

Temperature	Average	
	Minimum	Maximum
35°	750 σ	
39	371	1,105 σ
40	345	777
44	282	585
49	283	456

Alrutz

Temperature	Average Time
36.5°	805 σ
38.75	710
43.5	576
46.5	517
50	544

Alrutz points out that Goldscheider's figures show, as he contended, a greater effect of the stimulus temperature upon the hot reactions than upon the warm—i. e., a greater decrease in the reaction-time to the maximum than to the minimum, with increasing intensity of the stimulus. Since Alrutz found a parallel decrease in the reaction-time to paradoxical cold, as the stimulus temperature rose, he considers this conclusive evidence that the sensation of heat is due to the simultaneous stimulation of warm and cold nerves.

So far, Alrutz and Thunberg agree, but they differ as to the quality of the sensation. Alrutz considers it an unanalyzable fusion. His introspective reports show, he says, that hot is, qualitatively, a sensation having the same relation to warm and cold that orange

bears to red and yellow, similar sometimes to one, sometimes to the other, but never separable into the two components. Thunberg, on the other hand, calls hot an analyzable fusion—he thinks it possible to separate the element of paradoxical cold from the dominating hot sensation. At the third corner of the triangle stands Goldscheider, who considers hot simply as an intensive warm sensation, quite independent of paradoxical cold. In the study published in 1912 he takes up the argument of Alrutz point by point, and attempts to demolish it. In regard to the first argument, that on areas where cold spots are lacking no hot can be felt, Goldscheider finds that practically no such areas exist. (It will be remembered that he found a more numerous count of temperature spots than other investigators.) And if a refutation of the argument is needed, Goldscheider finds that in regions where there are sensitive warm spots, with scattered, not very sensitive cold spots, he is able to get quite as vivid hot sensations as on areas provided with strongly sensitive cold spots. The second argument, that regions that possess strong cold but weak warm sense will give hot sensations but never strong warm, Goldscheider meets again by the opposite experience: he gets warm and burning sensations but never hot. As for the third argument, that reaction-time for paradoxical cold agrees with that for hot and that therefore paradoxical cold is significant for hot sensation, Goldscheider considers this observation doubtful because of its great difficulty (he points out that only Alrutz himself made these observations), and that even if true, it is no proof of identity. He thinks the phenomenon much more explicable on the theory that a certain intensity of effect of a warm stimulus—which naturally must depend on a certain duration of the contact—raises the intensity of excitation of the warm nerves to the state where they give a hot sensation and that this intensity also provides the condition by which cold nerves are stimulated by warm stimuli. Other considerations too, especially that the hot sensation is strongest on areas where warm sensitivity is most strongly developed, persuade Goldscheider that Alrutz's theory is untenable. To this, of course, Alrutz would

reply that Goldscheider's determination of warm sensitivity was made by hot, not by warm stimuli, and that this is a circular argument. The question cannot be decided until unprejudiced observers have contributed enough evidence to outweigh these contradictory findings. At the present time, I think it might be said that psychologists incline to agree with Alrutz, while physiologists find themselves in accord with Goldscheider.⁴

The most systematic work in reaction-time to sensations of temperature has been done by Goldscheider (9c, p. 312 *et seq.*). He devised a rather ingenious device for measuring the time. The stimulus, a small brass sphere into which a thermometer was inserted, was arranged by means of levers so that its contact with the skin closed an electric circuit, its removal broke the circuit. The making and breaking of the current were noted by an electric marker on a smoked drum of a kymograph, on which a time marker, controlled by an electric tuning fork, indicated hundredths of a second. He found that the reaction-time depends upon the intensity of the stimulus, upon the threshold value of the sensation, and upon the sensitivity of the part of the body tested.

The difference in reaction-time of different parts of the body is shown in the following table:

	Stimulus 15° C.	Stimulus 50° C.
Face	.135 sec.	.190 sec.
Upper extremity	.150	.270
Abdomen	.226	.620
Lower extremity	.255	.790

The effect of the stimulus-temperature is shown in the following table. The region tested was the left forearm—an area moderately sensitive to cold, with a skin-temperature of 32.5°, and an area quite sensitive to warm, with skin-temperature 32.7°.

Stimulus-Temperature	Cold Reaction
30—29.5°	.399 sec.
28.5—28	.381
20—19	.377
15.5—15	.278

⁴ Except those who follow Head's theory of the constitution of the nerves; but Head, too, while he separates the mechanism for warm and hot impressions, postulates a simple sensory "heat spot." Cf. p. 128.

Stimulus-Temperature	Warm Reaction	
	Minimum	Maximum
35°	.750 sec.	
39	.371	1.105 sec.
40	.345	.777
44	.282	.585
49.5	.283	.456

It may be noted that for cold there is a marked drop in the reaction-time at 15°, while for warm the most marked drop occurs at 39°. The latter point is very much nearer the skin-temperature than the former—a result that, if constant, is a little puzzling.

CLINICAL INVESTIGATIONS

Following Fechner, interest was much stimulated to the investigation of thermal sensations. Nothnagel pointed out in 1866 that temperature sensibility was the first to be disturbed in diseases of the brain and spinal cord and in neuroses. He established norms of discrimination for various parts of the body, as has already been explained, with which clinical cases might be compared. He found hypo-esthesia to be the general rule—a raising of the threshold for discrimination. Often, however, in pathological cases, an apparent hyperesthesia occurs—an increased *effect* of a given temperature, apparently greater sensitivity—while discrimination remains normal or is reduced. This method did not prove very valuable, being too laborious and unnecessarily fine.

Donath next devised a method, on the assumption that the important thing clinically was to discover where temperature sensations passed over into pain. The method has been described. He applied it to the examination of thirteen cases of tabes, but curiously, he did not examine the same cases for both the warm-pain-threshold and the cold-pain-threshold. He found that warm-pain usually appeared at a higher temperature than normally, and cold-pain usually (though not always) at a lower. He concluded that the pain aroused by cold and warm was a much grosser sensation than the perception of moderate degrees of temperature and lacked the possibilities of discrimination of the latter. Neumann also investigated the pain threshold for warm stimuli. In four cases of tabes he found the

thresholds for warm and for pain higher than normal; in four cases of spondylitis he found two hypoesthetic in the affected region; in six cases of hysteria he found three normal, two hypoesthetic, and one hyperesthetic.

Goldscheider thought that the sensitivity of different areas would be a good clinical test (9a). He made a topographical map of the body on the basis of the intensity of sensation from the same stimulus, and then, in cases of disease, compared parts that normally had a constant relation to each other, to see if the sensitivity was affected. Obviously, the lack of any control for the introspective comparisons of clinical subjects would make this method of slight value.

The next clinical attempt was Leegaard's, who took as his point of departure the fact of the indifference zone—the region of the scale at and near the skin-temperature which is not felt as either cold or warm (13). He used little copper cylinders which were applied to the same spot for five seconds each, beginning at a temperature of 20°–25° C., and ascending by steps of .5° until the lower and upper limits of the indifference zone were reached. He found that normally the indifference zone was not over 1°, but in cases of brain and cord lesions and peripheral affections that he investigated, it might vary to any extent. In one case of hemiplegia, for instance, he found an indifference zone of 26°, in a case of transverse myelitis, an indifference zone of 14° in the affected region. These are rather interesting, because, while Leegaard did not differentiate two senses, and while his procedure was somewhat questionable, his experiments in a way anticipate those of Head.

The possibility of using tests of cutaneous sensitivity as a means of differential diagnosis, in the case of lesions of the nervous centers, is partly effect and partly cause of the more recently increased knowledge of conduction paths. Laehr did some important early work in distinguishing different types of partial sensory dissociation (12). In particular he pointed out the so-called syringomyelic type of dissociation, which is characterized by a disturbance of pain and temperature and the preservation of contact and pressure sensations. By 1905, four distinct types of dissociation

had been described. Marinesco (14) classifies them as follows:

(1) Deterioration of all forms of cutaneous sensibility.

(2) Abolition of pressure and vibratory senses (or one of these with conservation of all other forms).

(3) Abolition of thermic and pain senses with conservation of all others (syringomyelic type).

(4) Impairment of thermic, tactile, and pain senses with conservation of pressure and vibratory sensations.

An entirely new direction of work in the sphere of sensory dissociation has been suggested within the last decade by the work of Head and his colleagues. Head had the radial nerve in his arm divided, a small portion excised, and the ends sutured. Then he studied the return of sensation to the area of distribution of the nerve. His most complete report (18) was published in 1908. His findings were that sensitivity returned gradually: first, to pressure, cutaneous pain, and extremes of heat and cold, accompanied by the phenomena of intensification and peripheral reference of the sensation; and after a considerable interval (160 to 400 days) sensitivity to light touch, to moderate degrees of temperature, and the discrimination of two points simultaneously applied. His conclusions are familiar: that the skin is supplied by two systems of nerves—one providing for a more fundamental, reflex, diffused response to painful stimuli and the extremes of heat and cold ("protopathic sensibility"); the other producing localized responses, discrimination of light touches, of two points simultaneously applied, and of intermediate degrees of temperature ("epicritic sensibility"). More specifically, in regard to temperature he found that on the recovering area of the hand that was in a "protopathic" condition, punctate stimuli of about 17° C. were the first to be sensed; a little later, a stinging sensation in response to punctate stimulus of 50°, and then a sensation of heat from a stimulus of 45°. As sensitivity increased, the limits approached slightly nearer, but at no time while the hand was in a protopathic condition (*i. e.*, while it was insensitive to cotton wool and unable to discriminate two compass points), did any cold spot react to a temperature above 26° (except

paradoxically to a hot stimulus), nor did any "heat spot" react to any temperature under 37°. Only particularly sensitive spots reacted to these temperatures: the usual limits were about 20° and 40°. But simultaneously with the restoration of sensitivity to cotton wool, an areal stimulation (by a surface of 1.25 cm. diameter) of 36° to 34° gave a warm, well-localized sensation from parts where no "heat spots" had been discovered. Still, however, punctate stimulation of the "heat spots" gave no sensation if the temperature was under 38°. With cold, the experience was not quite so clear but seemed to Head analogous. With the appearance of the finer discrimination, no increase in the number of heat spots was observed; on the contrary, the separate spots lost their increased vividness. The recovered sensitivity to moderate stimuli, Head thinks, cannot be due to the regeneration of the nerve, because he finds that a similar condition obtains on the normal skin. If he marked out all heat and cold spots in a normal area, and then applied a stimulus between 26° and 37° to a small area where no spots had been found, such area would nevertheless respond with the appropriate sensation. He concludes therefore, that there are two mechanisms, one punctate, which responds to temperatures below 26° and above 37°; the other not punctate, which responds to areal stimulation between these two points.

The facts of adaptation Head finds offer further proof of different mechanisms. That epicritic sensibility depends on the temperature to which the skin is adapted, while protopathic sensibility does not, he concluded from the following observation: If both hands were adapted to water at 50°, a copper block at 29° felt cold to the normal hand, but gave no sensation on the protopathic area; similarly, after adaptation to 0°, it felt warm to the normal hand, but indifferent to the protopathic area. This is interpreted as meaning that the protopathic condition does not undergo the shifting of the threshold. When both hands were adapted to a cold of 10°, a paradoxical condition arose where 22° produced no sensation on the normal hand but gave cold sensation on the affected area. This is another evidence, Head says, of the fact

that the protopathic parts are incapable of adaptation, and so allow the cold spots to react to 22°.

This experiment has been repeated by several investigators. Franz (8) supported Head's contention that different sets of nerves provide for the reception of extreme and medium stimuli, but he regards the difference in sensation as due to an overlapping of the nerve supply—a possibility that Head rejects. Trotter and Davies repeated the experiment under elaborate and stringent experimental conditions (21). The results they obtained led them to conclude that all the observed phenomena were phenomena of hypoaesthesia due to the regeneration of the nerve fibers and that all forms of sensitivity tended to re-appear at about the same time in a hypoaesthetic form, except sensitivity to hot, which was somewhat delayed. Their observations in regard to sensations of temperature were practically identical with Head's, but their interpretation is quite different. Normally they say there is a zone of the temperature scale in the neighborhood of the skin temperature which is indifferent and extends over about five degrees of the scale.⁵ This indifference zone can be shifted up or down by warming or cooling the skin. As the distance between the skin-temperature and that of the stimulus is increased, the intensity of the sensation is increased, and it is generally necessary to have a difference of fifteen degrees before the maximum sensation is elicited. Now if there is a general reduction in the thermal sensitivity of the skin, this will produce an increase in the range of the intermediate insensibility, and a diminution in the intensity of the sensation produced by various stimulus temperatures. As an illustration: Suppose on the normal skin a stimulus of 32° is indifferent, 35° slightly warm, 38° warm, and 50° hot; if the skin is hypoaesthetic, then 32° and 35° will both be indifferent, 38° faintly warm, 50° warm, while hot perhaps cannot be elicited at all. This is what really happens, according to Trotter and Davies, in the hypoaesthetic zone of the recovering area, and partly accounts for the delayed reaction to hot. Nor-

⁵ This is a much wider zone than the results of any of the earlier investigators imply.

mally, a stimulus of 50° produces a sensation of hot, accompanied by a stinging quality; in the hypoaesthetic area, before any thermal quality is recognizable, a stinging sensation is produced by a stimulus of 50°.

Trotter and Davies' experiment was very carefully done and seems adequate to the facts it explains, but it fails to account for the cases reported by Head where epicritic sensibility remained after the protopathic type was destroyed. There is some evidence also to support Head's theory that the two sorts of sensibility are conducted by different spinal paths. Ranson has attempted to show histologically that the fibers that serve epicritic impulses are myelinated, enter the dorsal columns of the cord from the larger ganglia of the dorsal roots, and ascend on the same side; while those that serve protopathic impulses (pain, and extremes of temperature) are unmyelinated both peripherally and centrally, enter the cord from smaller ganglia, cross immediately to the other side of the cord and ascend in the lateral columns. Temperature impulses, however, are an exception to the uncrossed epicritic tracts, and, to provide for them, a few of the myelinated fibers were found to cross (17).

The literature leaves us then, in a rather inconclusive state as regards the nature of thermal sensations and the physiological conditions of their arousal. Authorities differ, on the one hand, as to whether hot is a simple sensation or a fusion involving both warm and paradoxical cold sensations; and, if a fusion, whether it can be analyzed or not. On the other hand, they are not agreed as to whether the facts of dissociation are to be explained by assuming different sensory mechanisms for extreme and medium stimuli, or by an overlapping nerve supply, or by a greatly diminished sensitivity. More clinical evidence of a searching character is needed before positive conclusions can be drawn.

EXPERIMENTAL

STATEMENT OF PROBLEM

The problem that I here present in its preliminary results is that of devising a clinical test of temperature sensitivity that may be

of some diagnostic value in certain diseases of the nervous system. The test used is a test of reaction-time to two distinctly different stimuli applied simultaneously. It was suggested by Dr. Tilney that a disturbance in the response to simultaneous stimuli of cold and hot might be apparent at an earlier stage than would appear from tests of either sensation alone, and might consequently be of early diagnostic value. This part of the experiment is concerned only with the responses of normal subjects, and the problem specifically stated becomes: What is the nature of the normal individual's reaction to two stimuli, one cold, one hot, applied simultaneously to immediately adjacent areas of the skin, in various regions of the skin surface?

APPARATUS

The stimulus was applied by means of little blocks of soft iron, attached to wooden handles, bearing a letter or number for ease of identification. These blocks were of two sizes, to suit the areas tested—the larger ones were two inches long, one and one-half inches wide and one-quarter inch thick; the smaller, one inch by three-quarters by one-quarter. There were ten of each size.

The blocks to be heated were kept in a bed of sand in a copper drying-oven, into the roof of which a thermometer was inserted—held by a cork—which reached to the bed of sand and recorded its temperature. The oven was heated over a Bunsen burner, and could be maintained at an accuracy of two degrees Centigrade range, which was considered sufficiently accurate for the purposes of the experiment, at least in its preliminary stages. It required a good deal of attention, however, to keep it at the desired temperature. The blocks to be cooled were placed likewise on a bed of sand, in a heavy zinc box which rested on a wooden rack, beneath which broken-up ice was placed. The box was also fitted with a cork into which a thermometer was inserted, reaching to the floor of sand. The accuracy of this device likewise varied within two degrees or less.

Before the testing began, a rough attempt was made to determine how long, under the conditions of the experiment, a block would

retain its heat. A hole was made in one of the blocks so that the bulb of a thermometer would fit into it, and some tests were made with this block. It was found that in a half-minute (which was as long as a block was ever kept out of the oven), of which time it was in contact with the skin from five to ten seconds, the block lost less than half a degree Centigrade, but that after returning the block to the oven it was four or five minutes before the block regained the oven-temperature. Enough blocks were provided so that no block was used oftener than once in five minutes, and only rarely oftener than once in seven or eight minutes.

It was desired for the purposes of the experiment to time the reactions in some simple fashion that would be suitable to use for clinical purposes. A stop watch could not be used, since both the experimenter's hands were occupied with the blocks; therefore a Thomas polygraph was used, so arranged that the experimenter could record the reactions with her foot. A tambour was so fixed that a light tap upon it with the experimenter's toe was transmitted to the writing lever of the instrument and made a mark upon the record paper. The polygraph was provided with a Jaquet chronograph, which marked fifths of a second. Writing pens were used, thus obviating the necessity of smoked paper, and the record could therefore be marked permanently as it was made.

MATERIAL AND METHOD

Five women acted as subjects for the experiment. They included a janitress of a flat and a college instructor; they ranged in intelligence from mediocre to superior ability, and in age from twenty-one to fifty years. They had no known nervous disturbances—except a slight neuritis reported once by one subject—although one subject was regarded as of a nervous temperament.

These five subjects were tested on forty test spots previously determined, each area being tested four times with the double stimulus—both cold and hot. An enumeration of the spots follows:

Area 1.—Fingers of right hand, dorsal surface. Area covered by two small blocks (held

with the long sides juxtaposed and the long axes running in a radio-ulnar direction) on the index and middle fingers, closely peripheral to the metacarpal bones.

Area 2.—Fingers of left hand, dorsal surface. Same area.

Area 3.—Right hand, dorsal surface. Area covered by two small blocks (held in same position) immediately proximal to second and third metacarpal bones.

Area 4.—Left hand, dorsal surface. Same area.

Area 5.—Right forearm, dorsal surface. Area covered by two large blocks (held with the short sides in juxtaposition and the long axes running in a peripherocentrad direction) which were set down proximally to a line drawn in a radio-ulnar direction one inch above the protuberance of the ulna, the long axis of the blocks coinciding with a line intersecting the first at right angles, one inch radiad to the protuberance of the ulna.

Area 6.—Left forearm, dorsal surface. Same area.

Area 7.—Right arm, lateral surface. Area covered by two large blocks (held with the long sides juxtaposed and the long axis at right angles to the axis of the arm) which were set down proximally to a line drawn two inches above the olecranon process of the ulna, the short axis of the blocks coinciding with a line joining the olecranon process of the ulna and the acromion process of the scapula.

Area 8.—Left arm, lateral surface. Same area.

Area 11.—Fingers of right hand, ventral surface. Area corresponding to that of Area 1.

Area 12.—Fingers of left hand, ventral surface. Same area.

Area 13.—Right hand, palm. Area corresponding to that of Area 3.

Area 14.—Left hand, palm. Same area.

Area 15.—Right forearm, ventral surface. Area corresponding to that of Area 5, but measured from protuberance of radius.

Area 16.—Left forearm, ventral surface. Same area.

Area 17.—Right arm, mesial surface. Area covered by two large blocks (held as for Area 7) which were set down proximally to a transverse line one inch above the crease made

by bending the elbow, the short axis corresponding with the line of the biceps. The latter line was measured from the inner condyle of the humerus, and the distance varied with the different subjects but remained the same for any one subject throughout the experiment.

Area 18.—Left arm, ventral surface. Same area.

Area 19.—Face, middle of forehead. Area covered by two small blocks (held with the long sides juxtaposed and the short axis in a cephalocaudad direction), set down so as just to clear the eyebrows.

Area 20.—Dorsal surface of neck. Area covered by two small blocks (held as for Area 19), set down in the median line, just below the hair.

Area 21.—Face, right cheek. Area covered by two small blocks (held as for Area 19), set down between the hair and the point of attachment of the lobe of the ear, just in front of the tragus.

Area 22.—Face, left cheek. Same area.

Area 23.—Right leg, lateral surface. Area covered by two large blocks (held with the short sides in juxtaposition and the long axis in a cephalocaudad direction) which were set down proximally to a line drawn transversely three inches above the external malleolus, the long axis of the blocks coinciding with a line intersecting the first at right angles, drawn upward from the same point.

Area 24.—Left leg, lateral surface. Same area.

Area 25.—Right leg, mesial surface. Area corresponding to that of Area 24, measured from the internal malleolus.

Area 26.—Left leg, mesial surface. Same area.

Area 27.—Right thigh, lateral surface. Area covered by two large blocks (held with the long sides juxtaposed and the short axis in a cephalocaudad direction), which were set down proximally to a line drawn transversely three inches above the outer condyle of the femur, the short axis of the blocks coinciding with a line drawn upward longitudinally from the same point.

Area 28.—Left thigh, lateral surface. Same area.

Area 29.—Right thigh, mesial surface. Area corresponding to that of Area 27, measured from two inches above the inner condyle of the femur.

Area 30.—Left thigh, mesial surface. Same area.

Area 31.—Right foot, sole. Area covered by two small blocks (held with the long sides juxtaposed and the long axis running transversely), set down at the intersection of two lines—a longitudinal line from the middle of the curve of the heel to the junction of the second and third toes, and a transverse line bisecting this.

Area 32.—Left foot, sole. Same area.

Area 31.1.—Right foot, dorsal surface. Area covered by two small blocks (held as for Area 31), set down proximally to the third and fourth toes.

Area 32.1.—Left foot, dorsal surface. Same area.

Area 33.—Abdomen, median line, caudad to navel. Area covered by two large blocks (held with the long sides juxtaposed and the long axis in a transverse direction), set down immediately caudad to the navel.

Area 34.—Abdomen, median line, immediately cephalad to navel.

Area 35.—Abdomen, right side. Area covered by two large blocks (held as for Area 33), set down at the intersection of a transverse line at the level of the navel and a longitudinal line three inches to the right of navel.

Area 36.—Abdomen, left side. Same area.

Area 37.—Back, median line. Area covered by two large blocks (held with the long sides juxtaposed and the long axis running transversely), set down caudad to a transverse line at the level of the lowest rib, the short axis of the blocks coinciding with the line of the vertebrae.

Area 38.—Back, median line. Area covered by two large blocks (held as for Area 37), set down cephalad to a transverse line four inches cephalad to the level of the lowest rib. (In the case of Subject G six inches was used instead of four.)

Area 39.—Back, right side. Area covered by two large blocks (held as for Area 37), set down at the intersection of the line at the

level of the lowest rib and a longitudinal line four inches lateral to the spines of the vertebrae.

Area 40.—Back, left side. Same area.

These forty areas were tested four times for each individual, twice with the hot block above the cold (*i. e.*, proximal or cephalad to it), and twice with the hot block below the cold (*i. e.*, distal or caudad to it). The two positions are referred to as Positions A and B respectively. Twenty-six of the areas were also stimulated with two cold and two hot blocks, separately.

The experiment was divided into two series, each consisting of sixty-six stimulations, forty with the double stimulus, thirteen with hot and thirteen with cold. The series were arranged in as nearly a haphazard order as was possible. Certain limitations were necessary, however, in order to make the experiment go smoothly. It was necessary, for example, to restrict the region tested in any group of stimulations to a part of the body that could be reached when the subject was lying in one position; it was not permitted to test the same area twice without a lapse of at least three stimulations between (to avoid disturbance from after-images); the hot and cold, large and small blocks had to be so distributed that no block was used oftener than once in five minutes, etc. The series finally took form as follows:

SERIES I

DOUBLE STIMULATIONS GIVEN IN POSITION A

Group 1. Right Arm and Hand

TEST	AREA		BLOCKS
1	11	cold	S 1, 2
2	5	—	L a, 1
3	3	hot	S a, b
4	17	cold	L 2, 3
5	11	—	S c, 3
6	15	hot	L b, c
7	13	—	S d, 4
8	3	—	S e, 5
9	17	—	L d, 4
10	5	hot	L e, a
11	1	—	S a, 1
12	15	—	L b, 5

Group 2. Abdomen and Face

TEST	AREA		BLOCKS
13	35	—	L 1, 2
14	34	—	L c, 3
15	21	—	S b, 2
16	36	—	L d, e
17	19	—	S c, 3
18	22	hot	S d, e
19	33	—	L a, 4
20	35	—	L b, 5
21	21	hot	S a, b
22	19	cold	S 4, 5
23	36	—	L c, 1
24	22	—	S c, 1

Group 3. Legs and Feet

TEST	AREA		BLOCKS
25	25	—	L d, 2
26	28	—	L e, 3
27	30	—	L a, 4
28	24	—	L b, 5
29	31	hot	S d, e
30	32.1	—	S a, 2
31	23	—	L c, 1
32	32	—	S b, 3
33	29	cold	L 2, 3
34	26	—	L d, 4
35	27	—	L e, 5
36	31.1	—	S c, 4
37	32	cold	S 5, 1
38	31	—	S d, 2
39	24	hot	L a, b
40	23	cold	L 1, 2
41	29	—	L c, 3
42	30	hot	L d, e

Group 4. Back, Neck, Lateral Surface of Arms

TEST	AREA		BLOCKS
43	39	—	L a, 4
44	40	cold	L 5, 1
45	8	—	L b, 2
46	38	—	L c, 3
47	7	hot	L d, e
48	20	—	S d, 4
49	37	—	L a, 4
50	8	cold	L 5, 1
51	40	—	L b, 2
52	7	—	L c, 3
53	39	hot	L d, e
54	20	cold	S 5, 1

Series I was given to three subjects on the first and third days, and to two on the second and fourth; while Series II was given to the former on the second and fourth days and to

the latter on the first and third. Practice tests were given to each subject before each group, on the areas included in the group, and the arrangement of the series was such as to distribute as evenly as possible the effects of practice.

Group 5. Left Arm and Hand

TEST	AREA		BLOCKS
55	16	cold	L 4, 5
56	18	—	L a, 1
57	4	—	S a, 2
58	6	cold	L 2, 3
59	2	—	S b, 3
60	12	—	S c, 4
61	14	—	S d, 5
62	18	hot	L b, c
63	4	hot	S e, a
64	16	—	L d, 4
65	12	cold	S 1, 2
66	6	—	L e, 5

SERIES II

DOUBLE STIMULATIONS GIVEN IN POSITION B

Group 1. Left Arm and Hand

TEST	AREA		BLOCKS
1	6	—	L a, 1
2	18	—	L b, 2
3	16	hot	L c, d
4	12	—	S a, 1
5	2	—	S b, 2
6	4	cold	S 3, 4
7	14	—	S c, 5
8	18	cold	L 3, 4
9	12	hot	S d, e
10	16	—	L e, 5
11	6	hot	L a, b
12	4	—	S a, 1

Group 2. Back, Neck, Lateral Surfaces of Arms

TEST	AREA		BLOCKS
13	40	hot	L c, d
14	8	—	L e, 1
15	38	—	L a, 2
16	7	cold	L 3, 4
17	39	—	L b, 5
18	20	hot	S b, c
19	8	hot	L c, d
20	40	—	L e, 1
21	37	—	L a, 2
22	39	cold	L 3, 4
23	7	—	L b, 5
24	20	—	S d, 2

Group 3. Legs and Feet

TEST	AREA		BLOCKS
25	29	—	L c, 1
26	23	—	L d, 2
27	31	cold	S 3, 4
28	32	hot	S e, a
29	30	cold	L 3, 4
30	26	—	L e, 5
31	29	hot	L a, b
32	32.1	—	S b, 5
33	27	—	L c, 1
34	25	—	L d, 2
35	31.1	—	S c, 1
36	31	—	S d, 2
37	24	cold	L 3, 4
38	32	—	S e, 3
39	28	—	L e, 5
40	23	hot	L a, b
41	30	—	L c, 1
42	24	—	L d, 2

Group 4. Abdomen and Face

TEST	AREA		BLOCKS
43	35	hot	L e, a
44	19	—	S e, 3
45	33	—	L b, 3
46	21	—	S a, 4
47	36	—	L c, 4
48	22	cold	S 5, 1
49	34	—	L d, 5
50	19	hot	S b, c
51	35	—	L e, 1
52	21	cold	S 2, 3
53	36	cold	L 2, 3
54	22	—	S d, 4

Group 5. Right Arm and Hand

TEST	AREA		BLOCKS
55	13	—	S e, 5
56	15	cold	L 4, 5
57	3	—	S a, 1
58	17	hot	L a, b
59	1	—	S b, 2
60	11	—	S c, 3
61	15	—	L c, 1
62	5	—	L d, 2
63	3	cold	S 4, 5
64	17	—	L e, 3
65	11	hot	S d, e
66	5	cold	L 4, 5

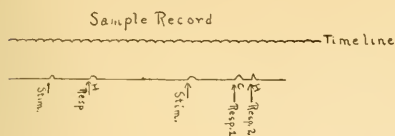
The temperature of the hot stimulus was 40°-42° C.; that of the cold stimulus was 18°-20°. A few variations beyond these limits are noted in the individual records of

Table 1. The room temperature varied from 21° to 24°. This temperature, somewhat higher than ordinary room temperature, was chosen because it was desired to keep the part of the body tested exposed. However, even this temperature was not comfortable for most subjects, and the covered parts of the body were not generally exposed for more than five minutes before they were tested. They were kept uncovered throughout the test of any region.

PROCEDURE

The subject lay on a cot in such a position that the experimenter, standing beside her with one foot over the tambour used to record the reaction, could, with very little movement, take the blocks from their resting places and set them down on the part to be tested. The subject was instructed somewhat as follows: "I am going to perform an experiment to see how you respond to hot and cold. When I put this little block down on your hand, I want you to tell me just as quickly as you can what you feel. Try it now" . . . (Several trials, either stimulus.) "Now I'll put both of them on you, and you tell me which you feel first, just as soon as you feel it; and then tell me just as soon as you feel the other. Close your eyes. Ready, on your arm!" Several trials were given, until S understood that she was to respond as soon as she felt anything. Some practice was required before S was able to respond with certainty on the first day, but thereafter there was rarely any difficulty. The directions were summed up, after S felt fairly sure of her replies: "Now you see what I am going to do. Sometimes you will feel both, and sometimes you will feel only one or the other, so you must pay close attention and answer what you feel just as soon as you feel anything." S then closed her eyes, the area to be tested was named; E removed the blocks from their boxes, started the polygraph, gave a ready signal, and set the blocks down, simultaneously tapping with her foot upon the tambour which operated the writing lever of the polygraph. S's responses were likewise recorded by a tap of E's foot, the blocks were returned to their boxes, the number of the test and S's verbal response (whether "cold-hot," "hot-cold," "cold," or

"hot") were noted beside the drum record of the reaction-time, and the second area was then tested in the same way. A sample of the record paper is reproduced below.



If the double stimulus was given and both cold and hot were reported, the stimulus was immediately removed. If both were given and only one reported, the stimulus was left in contact about five seconds and then removed. This same procedure was followed when only one stimulus was given, so that S's replies could not be controlled by knowledge of her errors.

If for any reason the record for any test was unsatisfactory—if the ink flowed too freely and blurred, if the tambour failed to record, if E was conscious of having bungled and given the stimulus badly, as occasionally happened—the test was repeated at the end of the group in which it occurred, without S's knowledge of its being a repetition.

When the record was completed, it was scored by counting the time marks between the moment of stimulation and the first response, and between the latter and the second response. To do this, lines were ruled from the rise of the recording mark to the time line by means of a straight edge. Readings were taken to the nearest tenth of a second.

CONDITIONS AFFECTING RESULTS

The reaction-time to cold has generally been found to be quicker than that to hot—a fact that corresponds to the probably deeper situation of the warm end-organs below the skin surface. It would therefore be assumed that if both stimuli were applied at the same time, other things being equal, the reaction to cold would precede that to hot. My results show that in most cases this is what happens

(v. Table 1), but the majority is in some cases so slight that it is important to consider the "other things."

LIMITATIONS OF METHOD.—In the first place, the limitations of the method must be taken into account. The method of measuring the reaction itself has a considerable possibility of error. The simultaneity with which E actually sets down the blocks and taps with her toe upon the recording tambour may be questioned. The error might be quite large in this case, for it is a fairly complicated procedure; nevertheless, I think the general consistency of each individual's responses (which may be seen from a glance at Figure 4) justifies the assumption that as a matter of fact this error was not large enough to affect the results materially. Then the recording of the subject's responses by E is also subject to a slight variable error; but this would undoubtedly be less—since E was practised before she began the tests—than the error of unpractised subjects in recording their own responses by unfamiliar means. The method of reading the record is also susceptible of a certain amount of error, which would not be greater in any case than one-tenth of a second. A more serious source of error, however, in the judgment of the experimenter, is the possibility of a slight inaccuracy in setting the blocks down exactly together and with equal pressure. An attempt was made to control this error by providing a tambour to be attached to the blocks, which would trace on the record the moment at which each block made contact with the skin. This device could not, however, be made to work satisfactorily. Consequently when the experimenter recognized that she had made a distinctly bad stimulation, she sometimes repeated it to see what the result would be. Sometimes also when the response was given in the order "hot-cold," the experimenter repeated the stimulus even though she thought it had been given accurately. This was not done systematically because it would have lengthened the experiment too much; but the following is a summary of the total number of times a test was repeated which first gave the response "hot-cold."

FIRST RESPONSE "HOT-COLD"

Subject	1st Badly Given		1st Not Badly Given	
	2ND RESPONSE		2ND RESPONSE	
	C—H	H—C	C—H	H—C
G.	7	—	1	—
Co.*	1	1	13	8
K.	—	—	—	—
H.†	1	—	4	1
Cl.	—	2	6	5

* One response was "cold" only. In one test that gave the response H—C, E thought that the cold block touched first, but this test was not repeated.

† One response was "hot" only.

Of twelve tests badly given and repeated, nine gave the response C—H, and three H—C on the repetition. Of thirty-eight tests repeated, though not consciously badly given, twenty-four gave the response C—H, and fourteen H—C on the repetition. This would seem to indicate that while some of the responses that occurred in the order H—C may have been due to inaccuracies of method of stimulation, some of them probably were not. This source of error, however, remains undetermined and probably considerable.

CHANGES IN TEMPERATURE OF SKIN OR STIMULUS.—In the second place the relation of the skin-temperature to the stimulus-temperature, and also the actual stimulus-temperature, may have affected the reaction-time in a variable way. Although the room temperature was fairly constant, the skin-temperature of different individuals on different days, on different regions of the body, probably varied rather widely. This is very likely one reason for the greater constancy of the reactions on the abdomen and back, which is shown by every figure—a less scattered distribution on these areas for each individual, a smaller variation among different individuals, and a higher percentage of responses in the order *cold-hot*. For, of course, the skin-temperature of the usually covered areas of the body varies less than that of the extremities and uncovered areas. The thighs and the back of the neck also show a greater constancy of response than the hands and feet. Variability of skin-temperature, then, will account for some of the variability of reaction.

The variations in the temperature of the stimulus constitute a possible source of error more difficult to determine. The hot stimulus varied for the most part between 40° and 42° C. On three days, a few tests were made with the oven temperature at 42.5°, one day it rose to 43°, and one day fell to 38°; but if the individual records for those days are examined, it does not appear that the general character of the results was affected (*v.* Table 1). The cold temperature varied between 18° and 20°, except on two occasions—once when it was between 18° and 16°, and once between 17° and 19°.

The hot stimulus temperature was chosen because it was desired to have a temperature distinctly hot, yet below the threshold for burning. This point of course varies; Neumann places it on the average at 43.5°, Head at about 50°. Temperatures below 40° frequently do not elicit a hot sensation. Therefore the limits were so set. In a similar way, a cold, distinctly cold but not painful, was desired. Crawford places the limit for great intensity of cold at 15°, and a temperature above 20° is not distinctly cold to a part of the skin whose temperature is 27°—as that of hands and feet often is. Therefore a temperature of 18°–19° was considered best.

The reaction-time depends, to some extent, on the temperature of the stimulus. Goldscheider found that for a limited area of the forearm, the mean reaction-time to cold for a stimulus of 20°–19° was .377 seconds; and for 15.5°–15°, .278 seconds—a difference of a tenth of a second for a range of four degrees. He also found that for a stimulus of 40°, the mean time was .777 seconds; and for 44°, .585 seconds—a difference slightly less than two-tenths of a second for a range of four degrees. Thus the variations in the stimulus temperature may have affected the results by a few hundredths of a second, but not significantly.

TOPOGRAPHY OF WARM AND COLD SPOTS.—In the third place, the number of warm and cold spots in the areas tested may have been unequal, and have given a different emphasis to one sensation or the other. This effect should have been neutralized by the procedure of reversing the relative position of the blocks in

alternate experiments. Nevertheless, slight discrepancies in the exact location of the spots might perhaps have thrown a strongly reacting spot into one-half or the other of any area, or one-half or the other may have contained a particularly sensitive spot of one kind. This possible source of error could not be corrected without a laborious exploration of the skin of every subject, which would not be worth while. It might perhaps be inferred that some idiosyncrasy of warm or cold spots is responsible

for those occasional instances when one area gave a hot-cold response in each of the four tests, or only one reaction to each test. Examples of this may be seen in Table 1: Subject Co., Areas 11, 14, 16; Subject H., Area 31. It may be noted that Area 13 in three subjects gave three responses in the order *hot-cold*.

These, then, are the factors that are or may be present in the results and should be borne in mind.

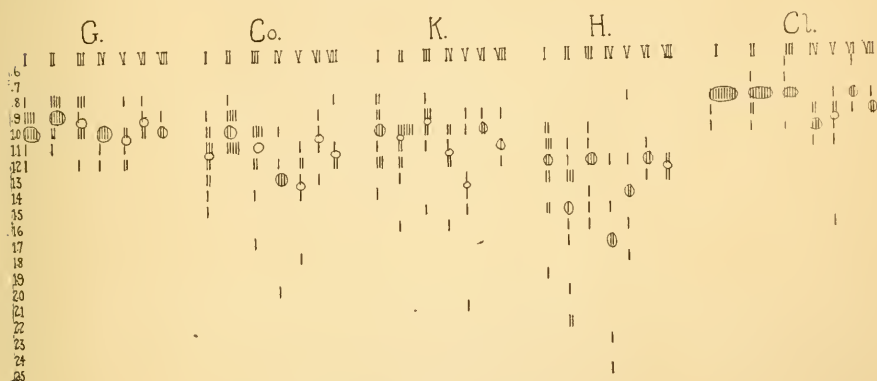


FIG. 1. DISTRIBUTION OF REACTIONS TO SINGLE STIMULI—COLD

Numerals I-VII indicate regions in order as follows: right arm, left arm, head, right leg, left leg, abdomen, back. Each stroke indicates time for one reaction on the region under which it occurs. Circles indicate medians for each region.

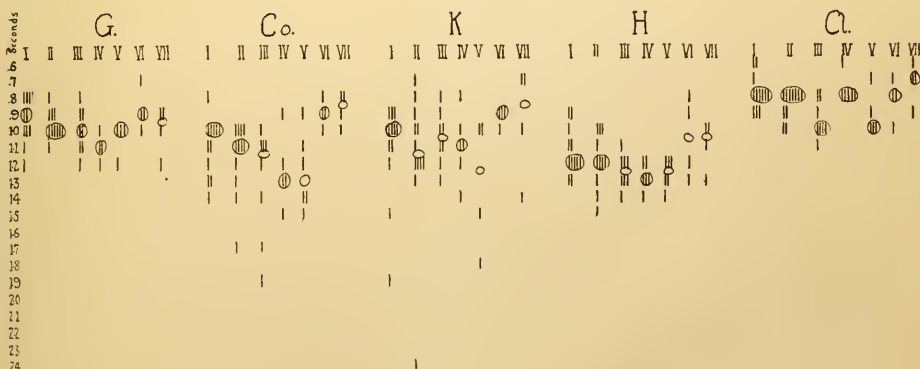


FIG. 2. DISTRIBUTION OF REACTIONS TO SINGLE STIMULI—HOT

TABLE I
REACTION-TIME (IN TENTHS OF A SECOND) FOR ALL DOUBLE STIMULATIONS

Subject G

Position of stimuli: Pos. A, Experiment 1 and 3; Pos. B, Experiment 2 and 4
 Temperature: H—Ex. 1, 42°-39.5° C.; Ex. 2, 40-42; Ex. 3, 41-42.5; Ex. 4, 40-42
 C—Ex. 1, 18°-19°; Ex. 2, 18-19; Ex. 3, 18-19; Ex. 4, 18-20
 Room—Ex. 1, 21-23°; Ex. 2, 23-24; Ex. 3, 24; Ex. 4, 21-23
 Dates of experiment: March 15, April 12, April 18, May 24, 1917

Area Ex.	Order C-H								Order H-C								Single Resp.			
	1st Intv.				2nd Intv.				1st Intv.				2nd Intv.				1 2 3 4			
1	10	10	12	8	5	4	3	3												
3	9	10	10	8	6	5	4	4												
5	10	12	9	9	4	5	4	4												
7	12	10	9	8	4	4	4	3												
11	18		11	10	4		4	4												
13	10	10	10"	9	4	3	4"	3	14'				4'							C13
15	9	9	10	8	3	4	4	3												
17	11	9	9	9	4	4	5	3												
2	13	10	11	9"	5	3	4	3"		11'										
4	12	12	10"	10	4	3	4"	4	9'				3'							
6	12	9	12	10	4	3	4	3												
8	10	9	9	8	4	4	4	4												
12		9	11	8		6	3	4	13				4							
14		11	9"	9		4	4"	4	11	9'			4		3'					
16	9	10	9	8	4	3	4	3												
18		9	8	10		4	3	3	9				6							
19		9		8		4		4												C10 C11
21	10	8	10	8	4	7	4	4												
22	10	10		8	4	4		7												C9
20		10	10	11		6	4	7	14				4							
23	10			8	11			7		12			3							C10
25	13	10	10	8	4	4	4	6												
27	11	10	8	9	5	4	3	4												
29	10	9	8	9	5	4	5	4												
31	13	14	10	11	4	4	6	5												
31.1		11	9	10		21	4	6												H12
24	8		8	8	13		4	5	12				4							
26	10	10	8	9	4	7	5	4												
28	9	10	8	8	4	4	4	5												
30	10	10	19	8	3	4	4	3												
32	15	10	10	10	5	4	10	4												
32.1	9	14	9	11	4	4	7	6												
33	9	9	8	8	4	4	4	4												
34	10	10	12	8	4	3	4	5												
35	9	8	9	9	4	4	4	3												
36	10	9	10	8	5	4	3	3												
37		10	11	8		4	4	4	8				4							
38	13	8	10	8	4	3	4	3												
39		12	10	8		4	4	3	9				3							
40		11	9	10		7	4	3	8				4							

C13

C10 C11

C9

C10

H12

TABLE I (continued)
REACTION-TIME FOR DOUBLE STIMULATIONS
Subject K

Area Ex.	Order C-H								Order H-C								Single Resp.			
	1st Intv.				2nd Intv.				1st Intv.				2nd Intv.				1 2 3 4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	14		10	12	4		3	4	10				6							
3	16		18		5		3		13				4							
5	13		15		3		3		9		10		5		3					
7				8				4	22	21	14		6	7	3					
11		10	11			6	3		9				5						B20†	
13				†					18	12	12	†	5	5	3					
15	14				5				10		11		4		4				B13	
17	11	12		8	5	6		4											B19	
2			10	11			3	3	12				4						H13	
4		14				6			16		14	14	5	4	4				B13	
6	10				4						9	10		4	4	4				
8	10		9	8	4		4	7		10				4						
12	12	11	19		5	4	4				13					6				
14			10	14			4	4	12				4						B17	
16		12				4			21				4						B12 C11	
18	14			12	4			4		9	14			3	4					
19		11		10		3		3	11		8		3		3					
21		10	9	9		4	4	3	16				5							
22	14		10	12	5		4	4		11				5						
20	13		12	9	4		4	3											B30	
23			11				4		12		12		4		4				B29	
25	10		18		6		3			14	11"		6		3"				B14'	
27	11	11			4	4					9				3				C8	
29	13	9	8	12	5	4	4	3												
31			18				4		28	18			5	6					B22	
31.1	17	10		13	5	16		8											H19	
24	21				5					16	18		4		4				B28	
26									22	9	10		4	4	4				B18	
28	11	10	9	11	6	4	8	4												
30	16	9	8	12	8	4	6	4												
32		12	12			4	15		13		14		9		4					
32.1	14		11	11	5		7	6											H22	
33	11	12	7	10	4	7	4	5												
34	11	10		10	7	3		5		8				3						
35	10	10	10		4	3	3				9				4					
36	11	10	9	10	4	4	4	4												
37		11		11		5		4	13				5						B37	
38	11	9	10	9	4	4	3	4												
39	13	10	8	10	3	4	4	4												
40	10	9		10	4	6		4		10				6						

† No record—test omitted.

‡ Reactions preceded by B are cases in which subject declared the sensations to be perceived simultaneously.

TABLE I (continued)
REACTION-TIME FOR DOUBLE STIMULATIONS

Subject II

Position of stimuli: Pos. A, Experiment 2 and 4; Pos. B, Experiment 1 and 3
 Temperature: H—Ex. 1, 38°–41° C.; Ex. 2, 40–42; Ex. 3, 40–42; Ex. 4, 40–42.5
 C—Ex. 1, 18–16°; Ex. 2, 17–17.5; Ex. 3, 17–19; Ex. 4, 18–20
 Room—Ex. 1, 22–23°; Ex. 2, 22; Ex. 3, 21–23; Ex. 4, 20–22
 Dates of experiment: March 13, April 10, May 3, May 15, 1917

Area Ex.	Order C-II								Order II-C								Single Resp.			
	1st Intv.				2nd Intv.				1st Intv.				2nd Intv.				1	2	3	4
1		13		14		11		31	12				6							H17
3	13	12			7	12				14				6						C15
5		12				4				15	14			9	19					H18
7		15		13		21		5		14				13						H28
11	18		16		6		4			14				3						H14
13				16				14	14	12	14		10	11	4					
15		10				4					15				30					H13
17		11				4			15		13		6		13					H15
2	16					5					19				21					H12*
4	26				18		12	12												H13
6			13	16				7	9											H14
8			11	14				7	9											
12	14	12	13	14'''	5	4	7	6'''				17'			10'					H15''
14	12		12		8			15		14		17		22		7				
16	15	12			6	5					18				12					C15
18	12	12		13	4	7		8		15				10						
19			14	14			4	6		14				5						H13
21	14	14		18	7	6		19			14				17					
22	10		21	20	6		4	19		14				8						
23		11		14		6		14		15				6						H14
25	13	12	14	13	7	8	5	11												
27				14				8	14	16			4		9					H16
29		15	15	13	8	5	6													H18
31				18				22												
31.I	13	13	13		6	5	6				16				17					C13 C14 H16
24	17	21		17	4	26		7												C12 C15 C18 C16
26																				H19
28	12	14	14	14	9	6	13	8												
30	16	19	17	19	5	4	6	5												
32	13	12	17		5	6	5													
34	12	12			5	6					15			12						C12
36																				H20
38		14				28														C11 C15 C14
40		16	15	14	20	6	10													H18
33																				
35		12		11		4		9		16				5						H16
37		11	13	11''		5	5	6''			18'				5'					H22
39		14	17			7	6				14				14					H16
41	12	11	14	14	5	4	4	5												
43	11	12	12	11	6	4	4	5												
45	10	12	11	18''	5	5	7	6''			10'					4'				
47	10	12	11	14''	4	5	5	6''			15'					5'				
49	13		11	13	5		4	24	12				8							

TABLE I (continued)
REACTION-TIME FOR DOUBLE STIMULATIONS

Subject Cl.

Position of stimuli: Pos. A, Experiment 2 and 4; Pos. B, Experiment 1 and 3
Temperature: H—Ex. 1, 40.5°-42° C.; Ex. 2, 40.5-42; Ex. 3, 40-42.5; Ex. 4, 40-42
C—Ex. 1, 17.8°-19°; Ex. 2, 18-20; Ex. 3, 18-20; Ex. 4, 18-20
Room—Ex. 1, 22°-23°; Ex. 2, 24-25; Ex. 3, 21-22; Ex. 4, 21-22
Dates of experiment: March 26, April 23, May 23 (a. m.), May 23 (p. m.), 1917

Area Ex.	Order C-II								Order H-C								Single Resp.			
	1st Intv.				2nd Intv.				1st Intv.				2nd Intv.				1 2 3 4			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	9	7	11		4	3	3					11				7				
3	9	9			5	3					12	9			24	4				
5	7	7"			5	3"			9'	9	8		5'	4	3					
7			9	8			5	7	6				11						C7	
11	12	7"			10	3"			7'	12	10*		7'	4	3*					
13	14	8	9"		4	4	4"			†	10*			†	4*					
15		6	9	8		4	4	3											H8	
17	8	6	8	8	4	3	4	3												
2		11"	8			4"	3		10'		8*		4'		8*				H8	
4	10				6				9	9*	8		6	4*	6					
6			8				3		8	9		8	5	6		6				
8	7	9	8	7	4	4	4	6												
12		8	8			4	5					8				4			C8	
14	10		10	11	6		8	4		9*				4*						
16		9		9		4		4	8		8		5		6					
18		10	8	8		4	4	4	10				5							
19	10	8			11	4					10	7			4	4				
21	8	9	10	9	9	3	4	4												
22		9				7					8				6			C8	C12	
20	9	8	9	8	5	6	5	4												
23	12	8"	9	8	5	8"	6	15		8'				5'						
24	10	8	10	10	16	10	8	6												
27	9	8	9	6	4	5	5	9												
29	8	8	8	8	4	5	4	4												
31	9	11	9		9	9	11												C12	
31.1		8	8	10		15	12	14	16				4							
24		7	9			16	7		9				4						C8	
26		9		9		14		10										C10	C8	
28	10	7	8	8	5	6	6	4												
30	10	6	9	8	4	4	6	4												
32		9	12	12		11	16	11	15				14							
32.1	9	8	9	10	11	21	28	12												
33	8		10	7	3		4	3	9				4							
34	9	8	10	8	5	4	4	4												
35	8	8	9	8	4	3	4	4												
36	8	8	10	8	4	4	6	4												
37	8	9	8	8	4	4	7	5												
38		8	8	7		6	12	5	8				4							
39	7	8	9	8	4	4	5	5					5							
40		8	8	9		4	9	3	9											

† Record could not be read, but response was in Order H-C.

* Stimulus was repeated and gave reaction in the same order.

EXPLANATION: Meaning of "Position of Stimulus" is explained under *Method*. Under "Order C-H" are grouped those reactions that gave response to *cold* first; under "Order H-C," those that gave response to *hot* first; under "Single Resp." those that gave either *cold* or *hot* alone, each figure designated by the appropriate letter. "1st Intv." means time from stimulus to first response; "2nd Intv.," time from first response to second response. Twice-accented figures indicate repetitions of the stimulus, to which the first response is shown by once-accented figures. Conditions under which repetitions were made are described under *Method*.

TABLE 2
REACTION-TIME (IN TENTHS OF A SECOND) FOR SINGLE STIMULATIONS

<i>Cold</i>												
<i>Subject</i>	<i>G.</i>		<i>Co.</i>		<i>K.</i>		<i>H.</i>		<i>Cl.</i>		<i>Av. M. V.</i>	
<i>Area</i>											<i>Seconds</i>	
3	11	10	13	12	10	19	9	12	8	9	1.04	.21
4	10	10	10	10	11	12	C14 H8	11	9	10	1.03	.07
11	8	9	8	11	11	9	12	12	8	8	.96	.15
12	10	9	11	11	12	10	12	13	8	8	1.04	.14
5	12	8	14	13	10	15	12	11	8	9	1.12	.20
6	12	10	14	11	12	24	12	14	10	7	1.28	.26
7	8	8	10	10	12	11	9	13	7	8	.96	.16
8	10	10	10	12	13	8	10	12	8	8	1.01	.13
15	10	9	10	10	9	10	10	12	8	9	.97	.08
16	11	9	17	13	10	12	10	15	8	8	1.13	.24
17	10	10	11	10	10	9	11	13	6	6	.96	.16
18	9	8	10	11	9	7	12	10	8	9	.93	.12
19	11	10	19	11	10	8	12	13	8	10	1.12	.20
21	10	9	11	10	10	11	14	13	11	10	1.09	.11
22	11	8	17	11	13	12	12	12	10	9	1.15	.16
20	9	12	12	14	11	9	11	13	10	9	1.10	.14
23	11	11	15	C11 H16	14	11	13	13	8	8	1.15	.20
24	C11 H4	10	12	14	C27 H6	C12 H9	12	13	10	9	1.14	.15
29	C11 H6	C8 H5	12	9	10	8	12	14	6	8	.98	.21
30	10	10	9	11	10	10	14	12	7	8	1.01	.13
31	12	10	13	13	12	11	12	13	8	8	1.12	.16
32	12	C9 H4	14	15	18	15	12	13	10	10	1.32	.20
35	10	9	8	10	10	9	9	12	8	7	.92	.11
36	9	C8 H4	9	9	9	9	8	13	10	8	.94	.10
39	10	9	8	10	7	10	10	11	6	7	.88	.14
40	12	9	8	9	14	17	13	10	7	9	1.08	.26

Temperature Sensitivity

TABLE 2 (continued)
REACTION-TIME FOR SINGLE STIMULATIONS*Hot*

<i>Subject Area</i>	<i>G.</i>		<i>Co.</i>		<i>K.</i>		<i>H.</i>		<i>Cl.</i>		<i>Av. M. V. Seconds</i>	
3	10	10	14	9	12	12	12	13	8	8	1.08	.18
4	9	10	11	11	13	12	17	16	8	8	1.06	.24
11	9	10	12	10	10	9	15	19	8	8	1.10	.26
12	9	9	9	9	12	11	12	20	8	8	1.07	.24
5	9	11	15	12	12	11	10	15	8	8	1.11	.19
6	9	8	11	10	10	10	22	13	10	8	1.11	.25
7	10	9	13	11	9	10	11	11	9	8	1.01	.11
8	11	8	11	11	16	11	13	13	7	9	1.10	.18
15	12	9	11	13	14	8	11	13	8	8	1.07	.20
16	8	8	8	9	10	10	H13 C6	15	9	8	.94	.19
17	10	8	11	10	10	8	10	12	10	8	.97	.11
18	9	10	10	9	10	10	11	22	8	8	1.07	.22
19	10	8	10	10	8	11	11	15	10	8	1.01	.13
21	8	9	10	10	10	9	10	12	8	8	.94	.09
22	12	10	17	14	9	15	12	14	8	7	1.18	.25
20	10	8	12	12	9	10	16	12	6	8	1.03	.22
23	10	10	13	13	10	11	15	23	10	10	1.25	.28
24	12	11	18	12	21	9	14	14	16	10	1.37	.28
29	10	12	13	10	12	10	17	12	9	9	1.14	.18
30	10	8	13	11	13	10	12	16	9	8	1.10	.20
31	10	11	20	12	12	16	25	17	10	11	1.44	.48
32	12	10	12	14	15	14	8	18	9	11	1.23	.23
35	10	8	11	10	10	10	11	12	9	8	.99	.09
36	9	10	13	9	H12 C8	9	12	13	8	6	.99	.19
39	H8 C4	10	12	12	H13 C6	9	12	12	8	9	1.05	.15
40	10	9	11	8	11	13	13	13	H10 C8	9	1.08	.16

TABLE 3
PROPORTION OF RESPONSES IN ORDER, C-H AND H-C*Cold—Hot*

<i>Subject</i>	<i>G.</i>		<i>Co.</i>		<i>K.</i>		<i>H.</i>		<i>Cl.</i>		<i>Av. % M. V.</i>	
	<i>No.</i>	<i>%</i>	<i>No.</i>	<i>%</i>	<i>No.</i>	<i>%</i>	<i>No.</i>	<i>%</i>	<i>No.</i>	<i>%</i>		
Right arm	31	94	13	34	14	45	12	38	21	57	53.6	17.6
Left arm	28	83	15	38	15	47	19	56	18	50	54.8	11.8
Head	12	75	10	59	11	62	12	75	11	69	68.0	6.0
Right leg	21	88	19	80	13	52	11	46	22	88	70.8	17.4
Left leg	23	96	12	48	14	59	17	71	19	80	70.8	14.0
Abdomen	16	100	11	65	14	88	11	64	15	94	82.2	14.6
Back	13	81	14	82	13	81	15	83	14	87	82.8	1.8
<i>Average</i>		88.1		55.3		62		61.9		75	69	

TABLE 3 (continued)

Hot—Cold

Subject	G.		Co.		K.		H.		Cl.		Av. % M. V.	
	No.	%	No.	%	No.	%	No.	%	No.	%		
Right arm	1	3	22	58	13	42	12	38	14	38	34.8	13.0
Left arm	6	17	23	59	12	38	9	27	16	44	37.0	12.0
Head	1	6	6	35	4	25	3	19	3	19	20.8	7.4
Right leg	1	4	1	4	7	28	3	13	2	8	11.4	7.3
Left leg	1	4	7	28	7	29	1	4	2	8	14.6	11.1
Abdomen	0	0	6	35	2	12	3	18	1	6	14.2	9.8
Back	3	19	3	18	2	12	3	17	2	13	15.8	2.6
Average		7.6		33.8		26.6		19.4		19.4	21.4	

TABLE 4

SINGLE RESPONSES TO DOUBLE STIMULI

Subject	G.		Co.		K.		H.		Cl.		Totals	
	C	H	C	H	C	H	C	H	C	H	C	H
Fingers	1	—	—	—	—	1	—	4	1	1	2	6
Hand	—	—	3	1	—	—	2	1	—	—	5	2
Arm	—	—	—	—	1	—	—	8	1	1	2	9
Face	3	—	1	—	—	—	—	1	2	—	6	1
Back of neck	—	—	—	—	—	—	—	—	—	—	—	—
Leg	1	—	2	—	—	—	—	2	3	—	6	2
Thigh	—	—	—	—	1	—	3	2	—	—	4	2
Foot	—	1	7	1	—	2	7	2	1	—	15	6
Abdomen	—	—	—	—	—	—	—	3	—	—	—	3
Back	—	—	—	—	—	—	—	—	—	—	—	—
<i>Totals</i>	5	1	13	2	2	3	12	23	8	2	40	31

TABLE 5

MEDIAN REACTION-TIME FOR SINGLE STIMULI—GROUPED BY SUBJECTS

Cold

Subject	G.			Co.			K.			H.			Cl.		
	No. of			No. of			No. of			No. of			No. of		
Region	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.
Right arm	.9	11	.10	1.05	12	.10	1.0	12	.05	1.2	12	.05	.8	12	.00
Left arm	1.0	12	.05	1.1	12	.10	1.15	12	.10	1.2	11	.10	.8	11	.05
Head	1.0	8	.10	1.15	8	.15	1.05	8	.05	1.25	8	.05	1.0	8	.05
Right leg	1.1	4	.00	1.3	5	.05	1.1	6	.10	1.3	6	.05	.8	6	.00
Left leg	1.0	4	.00	1.3	6	.15	1.25	4	.25	1.25	6	.05	1.0	5	.05
Abdomen	.9	4	.00	.9	4	.00	.9	4	.00	1.05	4	.15	.8	4	.00
Back	.95	4	.05	.85	4	.05	.85	4	.15	1.05	4	.05	.7	4	.00

TABLE 5 (continued)

Hot

Subject Region	G.			Co.			K.			H.			Cl.		
	No. of			No. of			No. of			No. of			No. of		
	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.	Med.	Cases	P.E.
Right arm	1.0	12	.05	1.1	8	.10	1.0	12	.15	1.2	12	.10	.8	12	.00
Left arm	.9	12	.10	1.0	12	.10	1.05	12	.10	1.5	11	.45	.8	12	.00
Head	.95	8	.10	1.1	8	.10	.95	8	.05	1.2	8	.10	.8	8	.00
Right leg	1.0	6	.05	1.3	6	.10	1.15	6	.10	1.7	6	.10	1.0	6	.05
Left leg	1.0	6	.10	1.35	6	.10	1.35	6	.25	1.4	6	.20	.95	6	.15
Abdomen	.95	4	.05	1.0	4	.05	1.0	3	.00	1.2	4	.00	.8	4	.00
Back	1.0	3	.00	1.1	4	.00	1.1	3	.20	1.25	4	.05	.9	3	.00

TABLE 6

MEDIAN REACTION-TIME FOR SINGLE STIMULI—GROUPED BY REGIONS

	Cold			Hot		
	Med.	No. of Cases	P.E.	Med.	No. of Cases	P.E.
Hand—dorsal (Areas 3, 4)	1.0	19	.05	1.1	20	.15
Hand—ventral (Areas 11, 12)	1.0	20	.15	.95	20	.15
Arm—dorsal (Areas 5, 6, 7, 8)	1.0	35	.15	1.0	40	.10
Arm—ventral (Areas 15, 16, 17, 18)	1.0	40	.10	1.0	39	.15
Face (Areas 19, 21, 22)	1.1	30	.10	1.0	30	.20
Neck—dorsal (Area 20)	1.1	10	.15	1.0	10	.20
Leg (Areas 23, 24)	1.15	16	.15	1.2	20	.20
Thigh (Areas 29, 30)	1.0	17	.15	1.05	20	.15
Abdomen (Areas 35, 36)	.9	19	.10	1.0	19	.10
Back (Areas 39, 40)	.9	20	.10	1.1	17	.15

NOTE: The lack of a complete total for any region indicates that the remaining responses were "cold-hot" or "hot-cold."

* P.E. in these tables is really Q, the semi-interquartile range, or the distance above and below the median that will include fifty per cent. of the cases.

TABLE 7

MEDIAN REACTION-TIME OF H-C RESPONSES

Subject Region	G.			Co.			K.			H.			Cl.		
	1st Int.	2nd Int.	No. of Cases	1st Int.	2nd Int.	No. of Cases	1st Int.	2nd Int.	No. of Cases	1st Int.	2nd Int.	No. of Cases	1st Int.	2nd Int.	No. of Cases
Right arm	—	—	—	1.2	.4	19	1.2	.4	13	1.4	.95	12	.9	.4	11
Left arm	1.0	.35	6	1.1	.5	20	1.25	.4	12	1.6	1.0	9	.8	.4	13
Head	—	—	—	1.1	.45	6	.95	.4	4	1.4	.8	3	.8	.4	3
Right leg	—	—	—	—	—	—	1.2	.4	7	1.6	.9	3	—	—	—
Left leg	—	—	—	1.3	.75	7	1.4	.4	7	—	—	—	—	—	—
Abdomen	—	—	—	1.3	.5	6	—	—	—	1.6	.5	3	—	—	—
Back	.8	.4	3	1.1	.6	3	—	—	—	1.2	.5	3	—	—	—

TABLE 8

MEDIAN REACTION-TIME FOR C-H RESPONSES—GROUPED BY SUBJECTS

First Interval

Subject	G.			Co.			K.			H.			Cl.		
	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.
Right arm	31	1.0	.05	13	1.1	.10	14	1.2	.20	12	1.3	.15	21	.8	.10
Left arm	29	1.0	.10	15	1.1	.10	15	1.1	.20	19	1.3	.10	18	.85	.10
Head	12	1.0	.10	10	1.1	.20	11	1.0	.15	12	1.4	.05	11	.9	.05
Right leg	21	1.0	.10	19	1.2	.20	13	1.1	.15	11	1.5	.20	22	.8	.05
Left leg	23	1.0	.10	12	1.3	.15	14	1.1	.10	17	1.4	.15	19	.9	.10
Abdomen	16	.9	.05	11	1.0	.15	14	1.0	.05	11	1.2	.15	15	.8	.05
Back	13	1.0	.15	14	1.0	.10	13	1.0	.10	15	1.2	.10	14	.8	.00

Second Interval

Subject	G.			Co.			K.			H.			Cl.		
	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.	No. of Cases	Med.	P.E.
Right arm	31	.4	.00	13	.4	.00	14	.4	.10	12	.65	.40	21	.4	.05
Left arm	29	.4	.05	15	.4	.00	15	.4	.00	19	.7	.20	18	.4	.05
Head	12	.4	.10	10	.45	.05	11	.4	.05	12	.7	.10	11	.5	.10
Right leg	21	.4	.10	19	.6	.20	13	.4	.05	11	.6	.20	22	.8	.30
Left leg	23	.4	.05	12	.4	.00	14	.55	.15	17	.6	.20	19	1.0	.45
Abdomen	16	.4	.00	11	.4	.10	14	.4	.05	11	.5	.10	15	.4	.00
Back	13	.4	.05	14	.45	.10	13	.4	.00	15	.5	.10	14	.5	.10

TABLE 9

MEDIAN REACTION-TIME FOR C-H RESPONSES—GROUPED BY REGIONS

Region	No. of Cases	First Interval		Second Interval	
		Med.	P.E.	Med.	P.E.
Hand—dorsal (Areas 1-4)	50	1.1	.15	.4	.10
Hand—ventral (Areas 11-14)	41	1.1	.15	.4	.05
Arm—dorsal (Areas 5-8)	50	1.0	.15	.4	.05
Arm—ventral (Areas 15-18)	46	.95	.18	.4	.00
Face (Areas 19, 21, 22)	40	1.0	.10	.4	.10
Neck—dorsal (Area 20)	16	1.15	.20	.5	.10
Leg (Areas 23-26)	53	1.1	.25	.6	.20
Thigh (Areas 27-30)	71	1.0	.20	.4	.05
Foot (Areas 31-32.1)	49	1.1	.20	.8	.35
Abdomen (Areas 33-36)	67	1.0	.10	.4	.05
Back (Areas 37-40)	69	1.0	.15	.4	.05

RESULTS

With these precautions concerning the reliability of the method we may consider the results. Table 1 presents the individual responses in detail to double stimulations for the forty areas. Table 2 presents the

detailed responses to single stimulations.

The first thing that may be noticed in a rapid inspection of Table 1 is the considerable number of responses that were given in the order *hot-cold*. Table 3 shows the proportion of responses in each order for each individual.

TABLE 10
COMPARISON OF REACTION TO HOT IN SINGLE AND DOUBLE STIMULI

	Double Stimulus C-H Resp.		Single	Difference
	(i. e., Total Time)	P.E.	Stimulus	
	Med.	P.E.	Med.	
Hand—dorsal	1.5	.25	1.1	.4
Hand—ventral	1.5	.25	.95	.55
Arm—dorsal	1.5	.15	1.0	.5
Arm—ventral	1.3	.15	1.0	.3
Face	1.5	.15	1.0	.5
Neck—dorsal	1.7	.25	1.0	.7
Leg	2.0	.25	1.2	.8
Thigh	1.4	.15	1.05	.35
Foot	2.0	.30	1.2	.8
Abdomen	1.4	.20	1.0	.4
Back	1.4	.15	1.1	.3

The averages show that on the arms the percentage of C-H responses is only slightly greater than half—53.6 per cent. and 54.8 per cent., while on the abdomen and back it rises to 82.2 per cent. and 82.8 per cent. respectively. These relations do not hold exactly among individuals, but a tendency toward greater constancy for the latter regions is shown by the fact that on these regions, in only two cases does the per cent. fall below 80, while on the arms (with the exception of Subject G., whose per cents. are all high), no case rises above 57 per cent. As regards the H-C responses, the highest percentages fall on the arms, on the average, and for all subjects except G.; but the percentages on abdomen and back are not significantly smaller than on legs. Individuals vary greatly—from G., who has no higher than 19 per cent. of H-C responses for any region, and no less than 81 per cent. of C-H responses, to Co., who has as high as 59 per cent. of H-C responses for one region and only 34 per cent. of C-H responses for another.

With these responses may be compared the cases in which only one response was made to the double stimulus (Table 4). It will be noticed from Table 1 that one subject, K, sometimes reported that both sensations were perceived simultaneously. This fact will be considered later. Excluding these responses of K., we find that there are 71 instances (out of about 800 responses) when only one of the

two stimuli is reported (*v.* Table 4). Of these, 40 are cold and 31 hot—a nearly equal distribution, but this is produced by the responses of one individual, H., who gave 23 hot responses; otherwise, the balance is in favor of the cold. With the exception of H.'s responses (which will be taken up again), nothing of particular significance appears from this table. These responses are probably to be explained by lapses of attention or slight inequalities in the stimulus.

The facts of Table 2 are more easily understood from Tables 5 and 6, and Figures 1 and 2, which attempt to present graphically the distribution of the reaction-times to separate cold and hot stimuli. The most striking thing about the distribution is the amount of overlapping in the reaction-times of cold and hot. The range in both cases is about the same, with a slightly greater variability for hot. The medians show no consistent difference for the two sorts of stimuli. In 20 cases out of 35 (*cf.* Table 5), the median cold reaction is shorter. In 14 of these, it is shorter by as much as .1 second, and in 9, by .2 second or more. In 10 cases the median for hot is shorter, and in the remaining 5 cases the medians are the same. This may be due to the rather rough method of measurement, since other observers have found a clearer difference; on the other hand, if the measurement adequately represents the fact, it explains, perhaps, the rather large number of

responses to double stimuli that occurred in the order, *hot-cold*. The averages for the individual areas (*cf.* Table 2) show the reaction-time for hot to be greater than for cold in 17 out of 26 cases—a slightly greater percentage of cases than appears from the medians of the grouped areas (Table 6), although in only 8 of these instances was the difference in time as much as .1 second.

It is of interest in passing to compare the median reaction-time to cold and hot separately (Table 5) with the percentages of C-H and H-C responses (Table 3), though it must be remembered that the medians of Table 5 are computed on too few cases to be very reliable. Still it is rather curious that Subject G., who showed fewest cases of H-C responses, nevertheless has more areas that give a shorter median reaction to hot than any other subject—three cases out of seven. A certain tendency toward consistency is, however, suggested by a comparison of Tables 3 and 6. Table 3 shows the greatest number of H-C responses, as well as the least number of C-H responses to occur on the arms. Table 6 shows that, with the exception of the back of the hand, the other areas on the arms have less than .1 second difference in the medians for cold and hot, one being greater for hot than for cold, one less, and one equal to cold. The abdomen and back, on the other hand, show .1 and .2 second difference respectively, the median for cold being shorter; and these areas likewise have the greatest number of C-H responses. This seems to indicate that the distribution of C-H and H-C responses is a real one and is not due exclusively to faults or inaccuracies in the procedure.

One other thing may be noticed about Table 6—the instances of double responses to the single stimulus. Some regions show an incomplete total for the group of areas designated, and the remaining number of responses were either “cold-hot” or “hot-cold.” Fifteen such responses were to cold, five to hot—that is, cold was more often felt as cold-hot than was hot felt as hot-cold. (H-C responses to cold and C-H responses to hot did not occur.) This is probably another illustration of the fact, often mentioned, that hot is a more diffi-

cult, less certain sensation than cold; so that any change or imagined change after cold is apt to be reported as hot. Subject Cl. so explained to herself several cases in which she reported the cold stimulus as “cold-hot” and then immediately corrected herself. (These cases, if included in the count, would further increase the difference.) Possibly the slight change in sensation was due to inexactness in setting down the blocks simultaneously and with equal pressure. The greater number of cold stimuli perceived as cold-hot may also, perhaps, be in part the effect of suggestion—more responses to double stimuli occurred with cold first; therefore greater likelihood existed that hot would follow cold than *vice versa*.

When we turn to the double responses, the hot-cold responses to double stimuli are not numerous enough to form a very accurate basis of comparison with the cold-hot responses. Table 7 shows the medians for those regions that have as many as three such responses. Of course most of these have a high degree of unreliability, but no particular differences from the distribution of cold-hot responses appear.

These responses may also be compared with the C-H responses in regard to the length of the interval between the first and second responses. In order so to compare them, the ratio of the second response to the first was determined for each response. The distribution of these ratios is presented in Figure 3. The medians for both sorts of responses are indicated by circles and crosses respectively. In twenty-two cases there were at least three H-C responses for a given region. Of these, five are equal to the median ratio for C-H responses for that region, five are less, and twelve are greater. That is, when the response occurred in the order *hot-cold*, there was a slight tendency for the second interval to be longer in relation to the first than when the response occurred in the order *cold-hot*. This is rather unexpected, and may perhaps be considered an intimation that in such cases the blocks were not applied quite simultaneously.

We may turn now to a study of the cases in which the response was given in the order

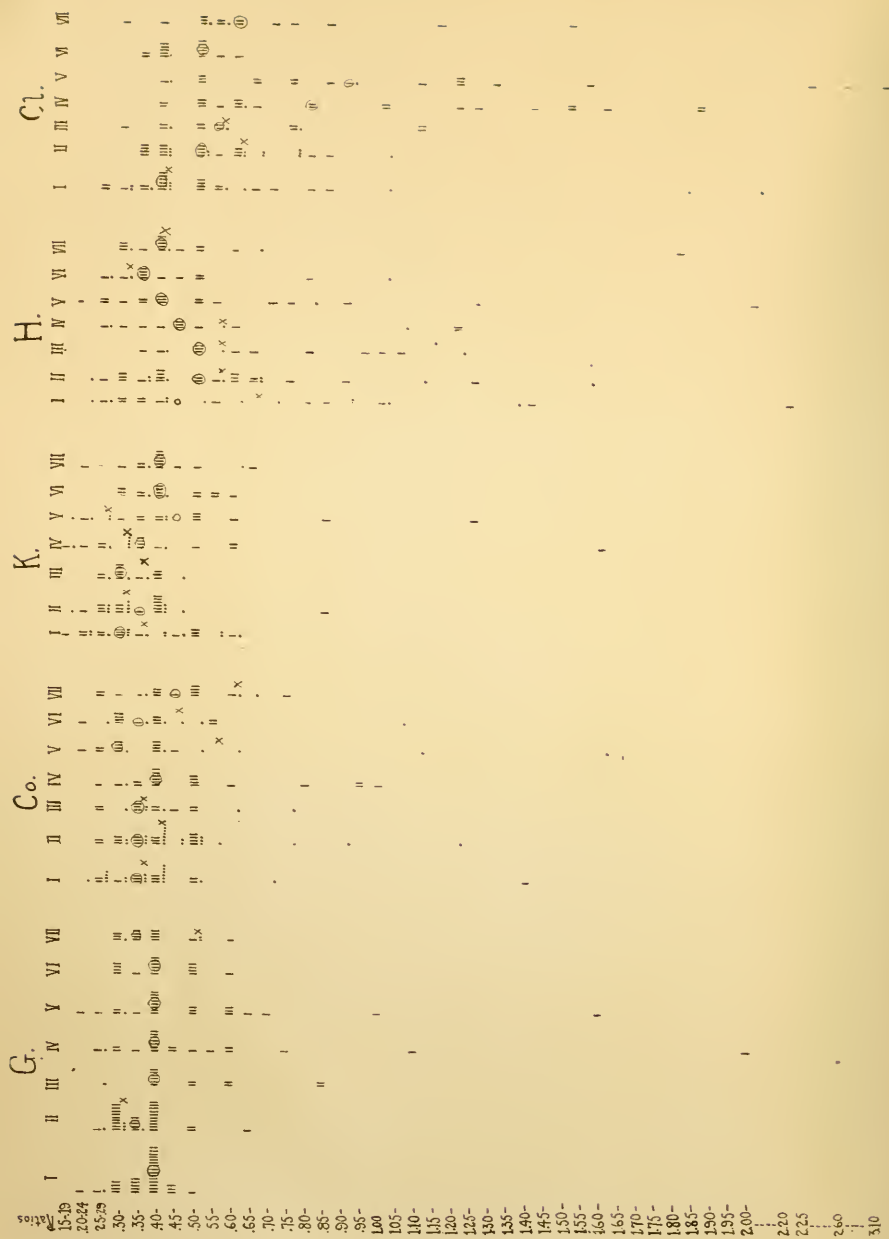


FIG. 3. DISTRIBUTION OF RATIOS ($\frac{\text{2nd Interval}}{\text{1st Interval}}$) OF COLD-HOT AND HOT-COLD RESPONSES FOR C-H, data for H-C responses; circles and crosses show the median ratios for C-H and H-C responses respectively for each region having at least three responses of the given sort.



FIG. 4. DISTRIBUTION OF COLD-HOT RESPONSES GROUPED ACCORDING TO SUBJECTS

cold-hot (*v.* Tables 8 and 9, Figures 4 and 5). Figure 4 shows the distribution for each individual and brings out such individual differences as there are. Subjects G., Co., and K. are quite similar as to median times and distribution; H. has somewhat longer times and more extreme reactions, but a similar difference in the median time of the two intervals; Cl. has a curious distribution, in that the median time for the second interval is relatively long—longer even than for the first interval, in one case. Four subjects show less variability for the second interval than for the first; that is, the second interval follows the first at a fairly constant interval of about .4 second, whatever the length of the first interval. In the case of Cl., however, the reverse is true. This accords with the fact shown by the distribution of ratios (*cf.* Figure 3): the ratio of the second interval to the first varies more than the second interval. Individuals vary least in reaction-time on abdomen and back (range of medians for these regions, .8–1.2 seconds—*cf.* Table 8), and most on legs (range of medians, .8–1.5 seconds).

The double stimulus, when cold is perceived first, does not appear much to affect the reaction-time to cold. Comparing the reaction-time to cold in the case of single and double stimulations (*cf.* Table 6 and Table 9), we find that three are shorter for the double than for the single stimulus, five are longer, and three are equal in the two cases.

The effect on the reaction-time to hot is,

naturally, to increase it. This may be seen by comparing the medians for the total reaction-time of C-H responses (*i. e.*, the time for the perception of hot in the double stimulations) with the medians for the reaction to hot separately. Table 10 presents the comparison.

The difference is about .4 second, on the average, but it is noteworthy that on the foot, leg and neck, the time is considerably increased for the double stimulus. This increase is due partly to a delay in the perception of hot for those regions, as the table shows. But this is not enough to explain the amount of difference in the reaction of these regions to double stimulations; the greater delay in this case must be in some way dependent on the double stimulation. It is possible that this is occasioned by the phenomenon referred to by Alrutz and Goldscheider as the *Anschwellung* of the sensation—the increase in intensity of the sensation immediately after the first perception of it—which is certainly most noticeable on the feet and legs. At this stage of the experiment, however, nothing definite can be said on this point.

Since the purpose of this paper is chiefly to present the facts as they appeared from an examination of normal subjects, the paper will close with a summary of the individual cases. The five individuals chosen were presumably normal. They were not given a neurological examination, but they were all personally known to the experimenter.

TABLE 11
SUMMARY OF INDIVIDUAL DIFFERENCES

	Total No. of Resp. to Double Stim.			Reactions Giving Range of Medians of Different Regions		Response C—H Areas Having Time less than 2 Resp. Greater than 2.5 Sec.		Ratio of 2nd Intv. to 1st Single Ratios Medians			Reaction to Sing. Stim. Med. for H. less than C	
	C—H	H—C	Sing.	No. of Cases	1st Intv.	2nd Intv.	No. of Cases	No. of Cases	No. of Cases	No. of Cases	No. of Cases	No. of Cases
G.	144	13	5	4	.1 sec.	0 sec.	0	0	2	3	0	3
Co.	94	68	15	11	.3	.2	10	2	3	5	1	2
K.	92	47	5*	11	.2	.2	10	3	14	2	1	2
H.	97	34	35	37	.3	.25	9	17	4	15	6	1
Cl.	120	39	10	7	.1	.6	3	4	0	23	6	2

* Thirteen cases were reported as simultaneous.

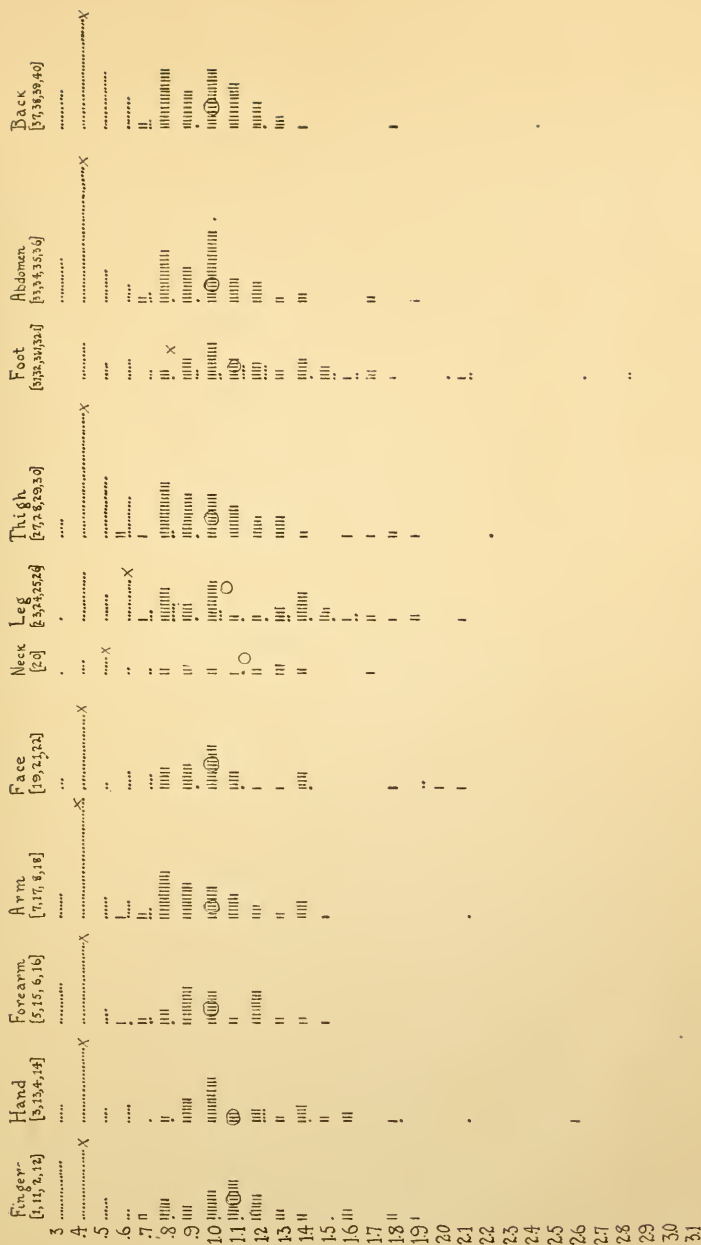


FIG. 5. DISTRIBUTION OF COLD-HOT RESPONSES GROUPED ACCORDING TO REGIONS

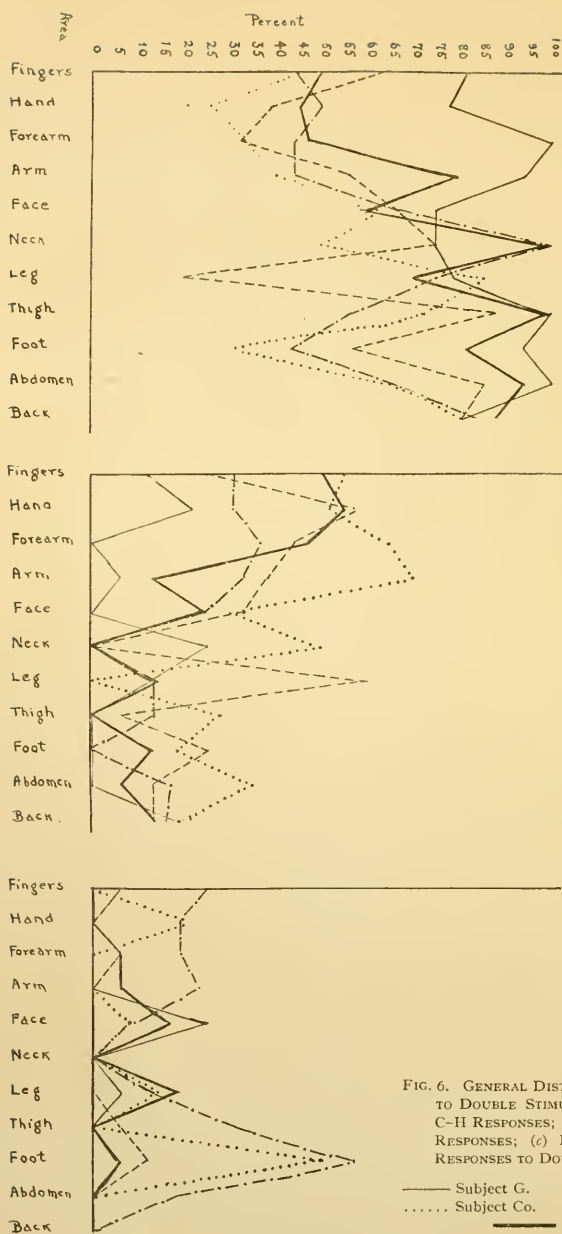


FIG. 6. GENERAL DISTRIBUTION OF RESPONSES TO DOUBLE STIMULI; (a) PERCENTAGE OF C-H RESPONSES; (b) PERCENTAGE OF H-C RESPONSES; (c) PERCENTAGE OF SINGLE RESPONSES TO DOUBLE STIMULI

— Subject G. - - - - Subject K.
 Subject Co. - . - . Subject H.
 ——— Subject Cl.

SUBJECT G.—A young woman of about twenty-one years of age, a student of domestic science, without any known nervous or temperamental abnormalities.

Compared with other subjects, G. showed a greater constancy of reaction in every respect. All the figures of distribution show a close grouping of her reaction-times—only four instances in the C-H responses when the reaction was greater than 1.4 seconds, only eighteen cases when the hot reaction preceded the cold, five reactions in which only one of the two stimuli was perceived, scarcely any variation in the median time for different areas for either first or second interval—but, on the other hand, three areas where the median for the separate hot stimulus was shorter than the median for cold; a close grouping of ratios, and no individual area which did not give at least two reactions in the order *cold-hot*. On the whole, G. is rather an ideal illustration of the norm.

SUBJECT Co.—A woman of about fifty years of age, without any known abnormalities.

The distribution of Co.'s responses is more variable but shows the same general characteristics as G.'s, except in the number of H-C responses. Seventy cases occurred, most of them on the arm, hand, or foot. It is to be noted (*cf.* Table 1) that the H-C responses that were repeated gave the same kind of response only on arm, hand, and foot—never on other regions. It is also noticeable that Area 11 gave no C-H responses but six in the order H-C; Area 14, no C-H responses but five H-C; Areas 3, 31, and 32.1 gave three single responses, and in the case of Area 31, all three were "cold." Co. shows a somewhat greater variability for different regions of the body than does G., with shortest median times on abdomen and back.

SUBJECT K.—A young woman of about thirty years of age, a graduate student in psychology—no abnormalities known.

K. also shows the same general form of distribution, with an intermediate number of forty-seven H-C responses. K. however, reported thirteen times that the sensation was simultaneous. This is rather curious,

since it occurred in no other subject, and it was probably the effect of suggestion. K. had heard a little about the experiment before acting as subject, and while she did not know the procedure, she evidently speculated a little about it. Toward the end of the second day she remarked that she supposed the blocks were put down simultaneously and she felt one before the other, because she did not perceive two contacts! It will be noticed from Table 1 that on the first day no cases of this sort appear. Nevertheless K. appeared to have some hesitancy in determining which sensation came first, and it is probably in consequence of this that she has fourteen ratios (compared with a small number in other subjects) less than .25, which indicates a relatively long first interval.

SUBJECT H.—A woman of about forty-five years of age, janitress of a flat, generally regarded as of a rather nervous temperament.

H. deviates somewhat from the general distribution of the first three subjects. Her reaction-time is longer, and she has more extreme reactions—thirty-seven of her C-H responses are greater than 1.4 seconds. Her total times are in seventeen instances greater than 2.5 seconds (compared with eight, the maximum for any other subject). Her ratios are also longer, fifteen being greater than 1.0, and six medians being more than .40-.44, the most frequent ratio. H. has thirty-five cases of a single response to a double stimulus—three areas giving a single response as many as three times out of four. Twenty-three of these were hot and twelve cold, reversing the proportions of every other subject but K., in whom the two sorts were practically equal. In contrast to this, it will be noticed from Table 1, that not infrequently H. responded by "warm" instead of "hot," although she was not asked to differentiate. It is true that for this subject on the first day the temperature of the hot stimulus fell to 38°; however, most of the "warm" responses did not occur on this day, and on other days the temperature was not below 40°.

SUBJECT Cl.—A young woman of about thirty years of age, a graduate student in psychology. On the second day Cl. was recovering

TABLE 12
SUMMARY OF REACTIONS

	<i>Cold— Separate</i>		<i>Hot— Separate</i>		<i>Cold—Hot</i>				<i>Hot—Cold</i>			
	<i>I</i>	<i>II</i>	<i>III</i>	<i>IV</i>	<i>1st Interval</i>		<i>2nd Interval</i>		<i>1st Interval</i>		<i>2nd Interval</i>	
					<i>V</i>	<i>VI</i>	<i>VII</i>	<i>VIII</i>	<i>IX</i>	<i>X</i>	<i>XI</i>	<i>XII</i>
Fingers	10	8-11	9	9-12	10	10-12	4	3- 5	12	10-13	5	4- 7
Hand	10	10-12	11	9-12	10	10-14	4	4- 6	12	10-14	4	4- 6
Forearm	10	9-12	10	9-12	10	9-12	4	3- 4	11	9-14	5	4- 6
Arm	10	8-11	10	8-11	10	8-11	4	4- 5	12	10-14	5	4- 7
Face	11	10-12	10	8-12	10	9-11	4	4- 6	11	10-14	5	4- 6
Neck—dorsal	11	9-12	10	8-12	10	9-11	4	4- 6	14	10-16*	4	4-12*
Leg	11	10-13	12	10-14	11	9-14	6	4- 8	12	10-16	4	4
Thigh	10	9-12	10	10-12	10	8-11	4	4- 5	12	12-15	5	4- 9
Foot	12	10-13	12	11-15	11	10-14	8	5-12	16	15-16	8	5-14
Abdomen	9	8-10	10	9-11	10	9-11	4	4- 5	13	10-16	5	4- 6
Back	9	8-10	11	9-12	10	8-11	4	4- 6	10	9-11	5	4- 6

* Total range: group included only three cases.

from an attack of neuritis in her left arm. This does not seem to have changed the character of her responses for this day or for her left arm in general.

The general character of Cl.'s responses shows quite individual characteristics—a markedly short reaction-time to hot and cold separately and to cold in the case of the double stimuli, but a delay in the reaction to hot on the legs, which made the median for hot, in the C-H responses, as long or longer than the median for cold. She has few extreme reactions, but all of them are to hot stimuli. Of the ten instances of single reaction to double stimuli, only two were "hot." In Figure 2 extreme reactions to hot separately may be noted on the left arm and right leg, while in Figure 4 nearly all the reactions that are extreme occur on the right and left legs and not at all on the left arm. Her ratios tend to be longer than the others; six medians are over .40-.44, and twenty-three separate ratios are greater than 1.0.

CONCLUSIONS

In so far as these five subjects may be representative of the normal reaction to cold and hot stimulation under the conditions of this experiment, we may summarize the results as follows:

1. More than half of the total number of

reactions to simultaneous cold and hot stimulation elicit first cold, then hot. The back and abdomen have a higher percentage than other regions of such responses.

2. The proportion of responses to double stimulation that does not include both responses is small—8 per cent. on the average, with a minimum of 3 per cent. and a maximum of 20 per cent.

3. The reaction-time to cold and hot stimuli separately does not show any distinct difference, as measured in this way, except perhaps on the abdomen and back.

4. The length of the first interval, when "cold" is the first response to the double stimulation, is about 1.0 second; the length of the second interval, about .4 second, on the average. A second interval of more than 1.0 second is rare.

5. The order in which the response occurs—whether "cold-hot" or "hot-cold"—is probably dependent in part on the simultaneity of application and in part on physiological conditions.

6. Individual differences in all of these respects are so considerable that a wide deviation from the average must be admitted as normal.

7. The method, though not accurate within very fine limits, gives a clinical picture sufficiently precise to show individual differences among normal subjects, and should

TABLE 12
SUMMARY OF REACTIONS

	% C—H	% H—C	% Sing.	% ?
	XIII	XIV	XV	XVI
Fingers	55.6	34.6	8.8	1.1
Hand	47.1	41.5	7.8	3.3
Forearm	50.6	36.1	6.0	3.6
Arm	58.2	32.6	7.4	1.3
Face	65.5	23.1	11.4	—
Neck—dorsal	84.2	15.8	—	—
Leg	64.6	18.3	9.7	7.2
Thigh	83.1	9.6	7.2	—
Foot	61.2	11.2	25.0	2.4
Abdomen	81.7	14.6	3.7	—
Back	83.1	15.7	—	1.2

therefore be useful in dealing with abnormal cases.

For convenience of reference, a table summarizing the data is appended. The first two columns of the table give, respectively, the median reaction-time in tenths of a second, and the limits between which 50 per cent. of the cases are included, for responses to separate *cold* stimuli. Columns III and IV give the same facts for separate *hot* stimuli. Columns V–XII contain similar data for responses to *double* stimuli, first for Cold-Hot, then for Hot-Cold reactions, and for each interval. Columns XIII–XVI show the proportion of double stimuli that gave responses of each kind: C–H, H–C, Cold or Hot alone, and Doubtful (where the priority of either could not be decided).

If individuals are to be compared with this table, it must be remembered that a subject's median reaction-time may lie anywhere within the limits of the probable error or even slightly outside of these limits and still be normal. The percentage of stimuli giving any particular sort of response is even more subject to individual variation. All that it would be safe to say about the normal reaction in this respect is that a majority of the total responses of an individual should be Cold-Hot, though on any region except the face, thigh, abdomen, and back the percentage may fall below fifty; and further, that a very small proportion of

the total will fail to give both responses, and that the neck, back, and abdomen are least likely to present this type. The graphs in Figure 6 will make this clear.

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A CONTRIBUTION TO THE STUDY OF TEMPERATURE REACTION IN NERVOUS DISEASES*

THE REACTION TO SIMULTANEOUS COLD AND HOT STIMULATION IN SYRINGOMYELIA, TABES DORSALIS, MULTIPLE SCLEROSIS, PERIPHERAL NEURITIS, AND A CASE PRESENTING A CAPSULO-THALAMIC SYNDROME

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OUTLINE

Introduction—Summary of the normal reaction to the double thermal stimulus

Consideration of individuals' reaction in the various phases of the test

Comparison of the syndromes studied

General tendencies observable in the reaction to double stimulation—tentative interpretation

Conclusions

The present study is a continuation of investigations of the reaction to a double thermal stimulus, preliminary results of which were published in the *NEUROLOGICAL BULLETIN* for March, 1918. The former paper dealt with the reaction of normal subjects. The present paper is a study of twenty-two patients suffering from organic nervous diseases.

The general method of the experiment was to provide several observations in each of which the reaction-time was measured for a series of stimuli combining simultaneous and separate cold and hot stimulation. For details of the method, description of the apparatus, plan of the series, etc., the reader is referred to the previous article.¹ The patients

included six cases of syringomyelia, five of tabes dorsalis, six of multiple sclerosis, four of peripheral neuritis, and one of a thalamic tumor. With the exception of one case of syringomyelia obtained from Dr. Tilney's private practice, they were patients from the Neurological Department of the Vanderbilt Clinic, and the diagnosis of each case was confirmed by the Chief of Clinic, Dr. McKendree. The experiments were made during 1917-1918, in the forenoons, in a room of the clinic, free from distraction, the temperature of which was kept between 22° and 25°C. As a rule, rather more preliminary practice was required with these patients than with normal

getting patients to return so often, the plan was varied so that three observations should give the same number of tests. On the first two days forty double stimulations were given as before, but the twenty-six areas were tested for both hot and cold. On the third day, two series of double stimulation were made, single stimuli being inserted only often enough to serve as a check. This was not a source of suggestion, however, because, as will be seen, all patients gave a considerable proportion of responses to double stimuli in which only one stimulus was perceived.

¹ The experiment as originally planned covered four days, on each of which the double stimulus was given on forty areas of the body, and a single stimulus on twenty-six of these areas—the latter being equally divided between cold and hot, so that in four experiments, two measures for cold and hot respectively were obtained for each of the twenty-six areas, and four measures of double stimulation were obtained for forty areas. Owing to the difficulty of

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subjects; enough was given to put the patient thoroughly at ease, and to give the experimenter an idea of the general type of response to be expected and a reasonable certainty that the patient understood the directions.

Analysis of the cases will be made, on the basis of the tables and figures to be found at the end of the paper, the cases of each syndrome preceded by a summary of the findings for that syndrome. The various syndromes will then be compared, the general nature of the disturbance will be discussed, and the conclusions that seem justified will be drawn.

As a preliminary, however, it will be convenient to summarize the results of normal reactions in a form easily comparable with that in which abnormal cases will be presented.

I. GROSS DISTURBANCE.—While normal subjects show many individual differences in the general nature of their responses, nothing that may be called a gross disturbance appears. By this term is meant a striking disturbance shown by *failure to react*; or by *perverted response* which is a hot-cold response to a cold stimulus or a cold-hot response to a hot stimulus, as well as a hot response to a cold stimulus or a cold response to a hot stimulus.

II. GENERAL CHARACTER OF REACTION.
Type of Response to Double Stimulus.—In spite of considerable fluctuation, normal subjects all show a majority of C-H responses, and a very small number of single responses.²

Range of Medians for Various Regions of the Body.—Among normals, no subject shows a range of more than .6 second for the median reaction-times of all regions, in any type of response. That is, a subject's reaction-time is fairly constant for all regions of the body.³

Extreme Reactions.—Since the measure used is the median and not the average time, it is not much affected by a few extremely long reactions. This is desirable, of course, in measuring the normal time, but in comparing abnormal cases with normal, it might cause the neglect of a number of extreme reactions, which might be of some importance. They

can, therefore, be considered by themselves. Reactions of 3.0 seconds for separate stimuli or for the first interval of double responses do not occur among normals.⁴ Reactions of 1.0 second or more as the second interval of double responses are rare, generally, though they occur in one subject in twenty-five per cent. of the cases.⁵

Consistency.—As it might be possible for a disturbance to be confined to a few areas, but at the same time to cause a large probable error in the measurement of the region including those areas, or a large fluctuation in the type of response for that region, the consistency of response was measured in the case of abnormal subjects (Infra, Table 8). For single stimuli, the measure used was the percentage of areas stimulated giving two correct responses—this is called consistency in type, and varies, for different normal subjects, from 85 to 100 per cent. for cold, and from 92 to 100 per cent. for hot. For double responses, the same measure was used—the percentage of areas stimulated giving two C-H responses, etc.; but this allowed more variation, as each area was stimulated four times. Consistency of C-H responses was high among normals, ranging for different subjects from 75 to 100 per cent.

The fluctuation of single areas in *time* might have been measured by the deviation of each area from its own average if there had been a sufficient number of cases, but it seemed best under the circumstances to take as a measure the range of each area having two similar responses. Thus, for normals, it was found that the percentage of areas which responded at least twice by C-H that had a very close range—less than .3 second—varied from 43 to 73 per cent. for the first interval, and from 45 to 80 per cent. for the second interval, for different individuals; while the percentage having a large range—1.0 second or more—was not more than 3 per cent. for the first interval, and varied from 0 to 29 per cent. for the second. In reaction-time, separate stimuli gave somewhat more consistent responses—68 to 96 per cent. of the areas having a small range for cold, 50 to

² Neurological Bulletin 1, p. 154.

³ *Ibid.*, Tables 5-8 and 11, p. 145 *et seq.*

⁴ *Ibid.*, Figs. 1, 2 and 4.

⁵ *Ibid.*, Table 1, Subj. H, p. 141.

92 per cent. for hot, while the largest percentage having a range of 1.0 second or more was 7.6 per cent.

Diminution of Intensity of Sensation.—While subjects were not asked to differentiate degrees of intensity, there were a few instances among normals, and many among abnormals, when the sensation was reported as 'warm', instead of the usual 'hot'. Isolated instances of this sort might be due to sporadic fluctuations in the temperature of the blocks used for stimulus; but any considerable number of such cases would have to depend on subjective factors. Of course, if all responses should be 'warm', it might be explained as a language-habit of the patient; but if any distinction is made, it is fair to assume that it represents a subjective difference. Among normal subjects, no responses to a separate hot stimulus were of this sort; in the case of double stimulation, the highest percentage of warm responses was 7 per cent. There was no suggestion of any corresponding tendency to report 'cool' instead of 'cold'.

Intensification of Sensation.—It would be desirable to have a measure of this phenomenon also, but as any questioning by the experimenter would have been a distraction from the main purpose of the experiment and would in any case have been too open to suggestion to be very valuable, it is necessary to resort to collateral evidence. There is much less tendency to report increase in intensity, verbally, than decrease; partly, perhaps, because a very intense stimulus causes a reflex withdrawal which is itself an evidence of increase. This reflex is about the only measure we have of intensification, and it is of questionable value both because of large individual differences and because no record was kept of its appearance in normal subjects. It occurred, on abdomen or back in at least two subjects, but it was generally inhibited in the course of the preliminary practice.

SYRINGOMYELIA

Six cases were studied. In three, the disturbance was confined to one or a few regions; while in the other three there is a general disturbance, although in two of the latter, it is more marked on a few areas. The distur-

bance is shown by a marked lengthening of the reaction-time to single stimuli; by failure to perceive the stimulus at times; by a tendency to give perverted responses; by a higher percentage of single responses than normal to double stimuli and a long reaction-time in every type of response; by a large number of extreme reactions; by a more than normal inconsistency of response; and by a tendency to report the sensation as weak in intensity. Analyses of the cases follow, with references to the tables and figures at the end of the paper.

CASE I.—P. K.; age 16; student; intelligence and coöperation good.

ONSET.—Spinal curvature eleven years before test.

SENSATION.—Not described in history.

I. GROSS DISTURBANCE.—Tables 6 and 7. No failure. Perversions occur on hand and arm to both cold and hot, but more often to cold.

II. GENERAL CHARACTER. *Type of Response.*—Fig. 1. Curve is practically normal for face and legs; but on arms, abdomen and back single responses to double stimuli are numerous:—H on arms; C on abdomen and back.

Median Reaction-time.—Table 1. In single stimuli C tends to be somewhat lengthened, except on face; while H is about normal except on arms and back. In double stimuli there is a general tendency toward lengthened reaction-time in the first interval of double responses; a marked similar tendency in the second interval on arms and back, and in the case of single responses.

Extreme Reactions.—Table 1, Fig. 6. Single responses show no more tendency to extreme reactions in double than in single stimuli, and are in both cases confined to cold. The tendency is more marked in double responses, and is more frequent for the second interval—slightly more frequent for H-C than for C-H type.

Consistency.—Table 8. In single stimuli there is a marked inconsistency in type of response for cold which is most evident on the right arm. The fluctuation in time, while greater than normal, is not very pronounced. In double stimuli no type of response occurs twice on half the areas, though C-H is the most frequent type. The fluctuation in time is greater than normal, and is particularly marked for the second interval of H-C responses. H responses fluctuate more than C.

Diminution of Sensation.—Table 9. Hot is diminished on all regions in a considerable percentage of cases—more in double than in single stimuli. Cold is somewhat diminished on arms.

Intensification.—Table 10. There is no reflex evidence, but patient reported that when sensation was 'sharp' distinction was difficult. He thought that it was cold that sent a shooting pain through region and that it 'got worse and worse' while warm 'stayed warm all the time'. Once he said: "I guess it's warm, because if it were cold I'd feel it." Perhaps this explains the number of times that C was reported as warm. It also implies an intensification of cold—though there is evidently a hypesthesia.

Single stimuli show cold to be more disturbed than hot: by its longer reaction-time; more extreme reactions; greater inconsistency in type and in time; and greater likelihood of perversion. But the results of double stimulation do not confirm this. The C-H type has at least a plurality of all responses; reaction to hot tends to be longer in double than in single stimuli, while to cold it remains about the same; and H responses are less consistent than C.

The disturbance is moderate in degree and is general rather than local, although face and legs escape.

CASE II.—E. Wi. (colored); age 25; dental student; intelligence and coöperation good.

ONSET.—About eighteen months before test.

SENSATION.—Described in history, July, 1917: "Mild degree of disturbance to hot and cold." Frequently patient burned himself because "sensation was so delayed he did not feel pain in time."

I. GROSS DISTURBANCE.—Failure to react was consistent on left hand. Perversion occurred on right hand to hot, and on left foot to cold.

II. GENERAL CHARACTER. *Type of Response.*—Curve is altogether comparable with normal, except for the failures on left arm and the per cent. of single hot responses on neck.

Median Reaction-time.—In single stimuli the only lengthening is for hot, on left arm and back. In double stimuli, C-H responses are about normal, but H-C and H responses show some lengthening, particularly on left arm and abdomen.

Extreme Reactions.—The highest percentage of extreme reactions occurred for single responses to double stimuli, thus indicating a real disturbance for this type, both in the failure to perceive the double stimulus and in the slowing up of the response

that did occur. In double responses the second interval is extreme more often than the first; but H is more frequently extreme than C, whether it is the first or second response.

Consistency. In single stimuli, H is less than normally consistent in type. The fluctuation in time is not excessive—though greater than normal—for either reaction. Both are very consistent (*i. e.*, they have a range of less than .3 sec.) in about half the areas. In double stimuli, no type occurs twice on fifty per cent. of the areas, though C-H approximates this. The fluctuation in time is greater than normal; and the deviation from the normal is greater in the C-H type than in the H-C.

Diminution of Sensation. Hot is diminished on all regions in a considerable number of cases—more in double than in single stimulation. The left arm, however, which showed the only gross disturbance, had relatively more reactions that were hot than had other regions. An initial perception of 'warm' followed by 'hot', from .3–2.0 seconds later, occurred a number of times but not with any regularity. 'Warm' was reported with temperatures even of 45° to 50°C. No weakening of the cold sensation was reported.

Intensification. No evidence, either reflex or verbal, was present.

Both single and double stimulations show more disturbance of the hot sensation than of the cold—more inconsistency in type; greater delay; more extreme reactions (at least in double responses); greater tendency to inhibition in double stimulation; and more tendency to diminished intensity.

Disturbance is marked locally, affecting, chiefly the left hand.

CASE III.—A. C.; age 31; tailor; intelligence and coöperation fair.

ONSET.—About nine years before test.

SENSATION.—Described in history, June, 1917: "Normal to touch and apparently, also to pin-point. Thermal sense absent down to shoulder joints."

I. GROSS DISTURBANCE.—Failures were frequent or usual on arms and neck, and occurred on abdomen. Sensation was entirely lacking on back, except on shoulder blades. Perversion of cold was the rule on arms and occurred on abdomen; perversion of hot occurred on left arm and abdomen.

II. GENERAL CHARACTER. *Type of Response to Double Stimuli.*—Curve shows almost complete absence of double response; C type present only on face, neck, and abdomen; all other responses H.

Median Reaction-time.—In single stimuli, reactions are all very prolonged—hot more so than cold. In double stimuli the H type only occurs with any frequency, and is even slower than in separate stimuli.

Extreme Reactions.—About half the single responses to double stimuli and single stimuli are extreme. Double responses are very infrequent, but evidently tend to be relatively longer for the second interval than for the first.

Consistency.—As patient came only twice, while the experiment was planned for four days, there were not enough stimulations on each area to provide a measure for consistency. But consistency for single stimuli could not be very high for either stimulus, because of the number of failures and perversions, while for double stimuli, forty-two and five-tenths per cent. of the forty areas gave two hot responses, and fifty-three per cent. of these had a range of more than 1.0 second.

Diminution of Sensation.—Diminution of hot occurred to a considerable extent on arms and abdomen, and to some extent elsewhere. 'Warm' was reported with temperatures as high as 47°C. Diminution of cold occurred on face.

Intensification.—On legs, the double stimulus and the cold stimulus were several times accompanied by a marked reflex withdrawal. In one such case—to cold—patient said: "Cold or hot—something strong."

Both sensations are much disturbed. Cold is more often perverted and is more apt to cause a reflex movement; and although hot is more delayed and apparently more diminished, it takes most marked precedence in double stimulation.

The disturbance is marked generally over all regions, but is profound on arms and back.

CASE IV.—L. A.; age 49; paper-hanger; intelligence and coöperation fair.

ONSET.—About ten months before test.

SENSATION.—Described in history, June, 1917: "Normal to pain and touch; cold felt as cold, but heat at times retarded and at times mistaken for cold on small finger and up ulnar side of forearm."

I. GROSS DISTURBANCE.—Failure to react occurred, but not persistently, on sole of each foot. Perversion of cold occurred on right forearm, right thigh, and right side of abdomen.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows preponderance of double responses except on arms and face, with H-C type more fre-

quent than normal. Single responses are frequent on arms and face and are present on legs; but do not occur on neck, abdomen or back.

Median Reaction-time.—Owing to the fact that patient came only twice, instead of four times, medians are not altogether reliable. For single stimuli, C seems to be a little slower than H—especially on face, left leg and abdomen, but times are not far from normal. For double stimuli, C-H responses are nearly normal, although face and legs seem to give rather long first interval and face a long second interval; H-C type tends to have more lengthened second intervals and generally longer first intervals; single responses are long.

Extreme Reactions.—The highest percentage of extreme reactions occurs for single responses to double stimuli, indicating, in connection with the long medians for this type, that these responses imply the most disturbance.

Consistency.—As in Case 3, consistency cannot be measured. It would be higher, with single stimuli, for H than for C, since the former had no errors. Results of double stimulation cannot be predicted; twelve and five-tenths per cent. of the areas gave two responses C-H, and an equal number gave two H-C.

Diminution of Sensation.—Hot stimulus was always reported 'warm'. Once, patient said: "Warm—good warm." As his English was somewhat limited, this may have been merely a language habit. No analogous cool was reported.

Intensification.—No evidence.

Contrary to the findings reported in the history, cold sensation seems to be more interfered with than hot, in both kinds of stimulation—it is slower separately and has more tendency to extreme reaction—in double responses as well as in single stimuli; only cold is perverted; and in double responses, hot takes precedence.

The disturbance is moderate and is general rather than local.

CASE V.—J. Cl.; age 21; accountant; intelligence and coöperation good.

ONSET.—About four years before test.

SENSATION.—Described in history, July, 1915: "Touch, deep sensibility, and position sense O. K. Touch uncertain (*sic!*); heat and cold not differentiated over arms and upper chest."

I. GROSS DISTURBANCE.—Failure to react. Complete absence of sensation on upper extremities, for hot stimulus up to 52°; and for cold to 16°. Ice felt

cold when grasped in hand, and cool on right forearm after several seconds. Perversion of cold was frequent, but in a number of cases a dubious correction was made. Indeed, patient was generally unable to tell, when he reported first one and then the other (whether the stimulus was double or single), whether both stimuli were present or whether he had first made a mistake—the second sensation seemed to take the place of the first.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows marked predominance of H type, but greater frequency of C-H than of H-C. C responses are infrequent except on face.

Median Reaction-time.—Reaction-time is practically normal. In single stimuli C seems to be a trifle slower than H, and a little delayed on abdomen. In double stimuli, second interval is slightly long in double responses; single responses are prompt except in the case of C responses on back.

Extreme Reactions.—The only tendency to extreme reactions is in the case of the second interval of double responses, where half the reactions are over 1.0 second.

Consistency.—Except for the marked inconsistency in type of separate cold stimuli (due to the frequent perversions) and a larger than normal fluctuation for this type, patient's responses are very consistent in both type and time; but in double stimuli, it is the H type, not C-H, that is consistent.

Diminution of Sensation.—No diminution of sensation occurred in the first report; but twice on the cheeks, the double stimulus, although reported 'hot', evoked the comment: "It didn't feel either way afterward"—"it was just lukewarm afterward." A response of 'hot' was also occasionally followed by "a little cold at beginning."

Intensification.—There was no evidence of this.

Except for the anesthetic regions, hot seems to be intact; while cold shows some disturbance—its perversion; its slightly longer time; its inhibition in double stimuli; the fact that when the double stimulus was perceived, hot was more likely to follow when cold was felt first; and the few cases when cold was perceived without hot; are evidence of this.

The disturbance is complete locally, and is slight generally.

CASE VI.—B. T. (female); age 22; stitcher; intelligence and coöperation fair.

ONSET.—About eight years before test.

SENSATION.—Described in history, October, 1917: "Over areas corresponding to sixth to eighth cervical segments of cord, on right side, there is diminished pain and temperature

sensation, but touch is but slightly diminished."

I. GROSS DISTURBANCE.—Failure to react was the rule on left arm and was frequent on right arm. Perversion of cold was uniform on right arm.

II. GENERAL CHARACTER. *Type of Response.*—Curve is normal except on arms and face.

Median Reaction-time.—Number of cases is few, because patient came only once. Times seem to be somewhat longer than normal in all cases except the second interval of double responses. This may be due to insufficient adaptation to the task or is, perhaps, an individual characteristic. The longest times are for H responses to double stimuli.

Extreme Reactions.—Occur with frequency only in single responses to double stimuli.

Consistency.—Cannot be measured from one observation.

Diminution of Sensation.—All hot stimuli (temperatures 40-44) were called warm.

Intensification.—There was no evidence.

The perversion of cold and the fact that single responses to double stimuli were more often 'hot' than 'cold', suggest that cold is somewhat more disturbed than hot.

The disturbance is local and quite marked.

TABES DORSALIS

The five cases studied show some disturbance of a general character—marked in two; slight in two; and moderate in one. The disturbance is shown by some tendency toward perversion; by a marked deviation from the normal type of response; by a tendency toward somewhat lengthened reaction-times—especially with the double stimulus; by the number of extreme reactions; the inconsistency of response; and by a tendency toward intensification of the sensation. Analyses of the cases follow:

CASE VII.—G. C.; age 39; barber; intelligence rather inferior.

ONSET.—About two years before test.

SENSATION.—Described in history, June, 1917: "Hypesthetic to pin-prick and to cotton wool."

I. GROSS DISTURBANCE.—No failure to react. Perversion of cold occurred consistently on lateral surface of both legs.

II. GENERAL CHARACTER. *Type of Response.*—

Curve shows more single reactions than normal on every region except, perhaps, the face; being particularly high on legs, abdomen and back. H-C responses are slightly more frequent than C-H. There is a considerable number of doubtful responses.

Median Reaction-time.—In single stimuli all regions give lengthened times except neck, abdomen and back for H; and C is somewhat slower than H. In double stimuli, C-H responses show much lengthened first interval and long second interval on left leg and back. H-C responses are long in both intervals. Single responses are also long, H somewhat less than C.

Extreme Reactions.—Extreme reactions are frequent—more so in double than in single stimuli, and more for the first interval and for single responses than for the second interval. The tendency for both intervals is more evident in H-C than in C-H type.

Consistency.—Reaction to all kinds of stimulus is very inconsistent in type and fluctuating in time, except for the first interval of C-H responses.

Diminution of Sensation.—Diminution of hot occurred to some extent in both single and double stimuli; cold was diminished to a much greater degree than in other subjects, chiefly in double stimuli.

Intensification.—Some reflexes were present but were not very marked. They accompanied cold stimulation and double stimulation, and were mostly on abdomen and back.

Cold is evidently somewhat more disturbed than hot—it is more lengthened; shows some perversion; occurs somewhat less frequently than H as the first response; and is considerably diminished in intensity.

The disturbance is quite marked and is general rather than local.

CASE VIII.—P. O.; age 36; railroad man; intelligence and coöperation good.

ONSET.—About three years before test.

SENSATION.—Described in history, May, 1917: "Touch and pain showed hypesthetic region on back, with bordering hyperesthetic area. Vibratory sensation diminished on lower extremities." (Temperature not mentioned.)

I. GROSS DISTURBANCE.—No failure to react. Perversion of hot on soles of feet; of cold on back.

II. GENERAL CHARACTER. *Type of Response.*—All are rather frequent. On the legs, C-H and C predominate; on neck and back, H.

Median Reaction-time.—In single stimuli medians are about normal, but H is somewhat quicker than C. In double stimuli the reaction is slower and more variable; first interval of C-H and second interval of H-C are about normal. H responses are generally slower than C.

Extreme Reactions.—In single stimuli extreme reactions are rare and occur only for C. Double stimuli increase the number of extreme reactions, particularly for single responses and for second interval of double. Hot, either as first or second response, is more apt to be extreme.

Consistency.—In single stimuli, consistency in type is normal for both, but fluctuation in time is marked for C. In double stimuli, no type gives even a moderate degree of consistency; in time, the fluctuation is greater than for single stimuli and is noticeably greater with C-H than with H-C responses.

Diminution of Sensation.—There is no evidence of this.

Intensification.—Reflex retractions, sometimes so pronounced as to interfere with stimulation, occurred on legs, abdomen and back, chiefly accompanying double stimulus. They were most violent on back, and increased rather than diminished as experiment progressed. Patient declared the stimulus felt 'scalding' and 'icy'. With separate stimuli often, and not infrequently with double, patient reported a second hotter or colder sensation from one to four seconds after first.

Although in single stimuli C is somewhat slower and more apt to be extreme than H—as well as more fluctuating—in double stimuli, the opposite is the case: hot is delayed more, whether as first or second response or whether it occurs alone, and is more apt to be extreme, although it is still less fluctuating than cold.

The disturbance is moderate and general, though less marked on upper extremities.

CASE IX.—J. Co.; age 37; tailor; intelligence good, coöperation fair.

ONSET.—About seven years before test.

SENSATION.—Described in history, October, 1917: "Hypesthesia partial to pain and vibratory sensation."

I. GROSS DISTURBANCE.—Failure to react occurred, chiefly with hot stimulus on sole of left foot. Perversions of both stimuli occurred—of hot on face; more often of cold, on foot and back.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows C-H responses in general to be most frequent; H-C very infrequent; C almost absent

except on legs where they predominate; H very frequent on right arm, abdomen and back.

Median Reaction-time.—The only tendency toward lengthening of reaction-time occurs for the second interval of H-C responses.

Extreme Reactions.—The number of extreme reactions is small. It is greater for single stimuli than for double, except in the second interval, and occurs only with hot stimuli.

Consistency.—In single stimuli, consistency in both type and time is quite normal. In double responses, while no type has a very high consistency, the C-H type attains it in forty-five per cent. of the areas. The fluctuation in time is not great.

Diminution of Sensation.—There is a considerable tendency to report 'warm' instead of 'hot'—slightly greater in the case of double than of single stimuli. Twice, an initial perception of warm was followed by hot, not more than 1.5 seconds later. No diminution of cold was reported.

Intensification.—Stimulation on back was sometimes accompanied by a reflex, but the tendency was not marked, and there was no verbal comment.

The type of response suggests that on the legs the hot sensation is more interfered with than the cold; elsewhere there is not apparent a greater disturbance of one than the other, except in the rather general tendency toward a diminution of the intensity of hot.

The disturbance is very slight, but general.

CASE X.—L. F. (female); age 53; cook; intelligence rather inferior; coöperation poor, influenced by suggestion.⁶

ONSET.—About two years before test.

SENSATION.—Described in history, September, 1917: "Normal."

I. GROSS DISTURBANCE.—No failure to react. Perversion of cold was general—the response usually H-C. This was evidently due, at least in part, to suggestibility and inference, as H-C responses were frequent to hot stimulus also. When error was pointed out to her on third day, the number of wrong responses was reduced to four, all of which occurred on arms and legs.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows H-C type to be decidedly predominant,

⁶ Patient was unduly impressed by instruction to react as quickly as possible, and evidently inferred that nearly all stimuli were double. She seemed to think the test a 'treatment' and to consider the stimulus more important than the response. On the third day her error in giving double responses to single stimuli was pointed out, and the error was reduced, though not eliminated, by her increased attention.

but its significance is questionable, as single stimuli also gave this response most frequently. Single C responses occur only on arms and legs; H only on abdomen and back.

Median Reaction-time.—In single stimuli, while there is much variability owing to the small number of correct responses, no significant tendency to long reaction-time is apparent. In double stimuli, the only lengthening occurs for the second interval of both C-H and H-C responses on the face, and in general for C responses.

Extreme Reactions.—There is no very marked tendency to extreme reaction. It is perhaps most significant in single responses to double stimuli; but while in single stimuli all extreme reactions are to hot, in single responses to double stimuli they are all to cold.

Consistency.—In spite of three trials instead of two for each area, single stimuli gave a low degree of consistency in type and a larger than normal fluctuation in time. Double stimuli—with three instead of four trials—were quite consistent in the H-C type. Fluctuation in time was not marked and was normal for second interval of both types.

Diminution of Sensation.—There is no evidence of this.

Intensification.—Reflexes are very numerous and occur on left arm and face as well as legs, abdomen and back. They occur more with single than with double stimulation and more with cold than hot. On abdomen, patient, asked which was more intense, called the cold (of 19°) 'worse' than the hot (44°).

One can hardly say that either sensation is more disturbed. At least a tendency for hot to take precedence, in spite of apparently greater intensification for cold, seems to be present.

There is evidently a slight general disturbance the real nature of which is, however, masked by patient's desire to 'do well'.

CASE XI.—H. D.; age 49; metal lather; intelligence and coöperation good.

ONSET.—About three years before test.

SENSATION.—Described in history, June, 1917: O. K. (except blurring vision).

I. GROSS DISTURBANCE.—Neither failure nor perversion occurred.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows a marked predominance of C, with infrequent double responses.

Median Reaction-time.—Reaction is generally quite slow. In single stimuli C is slower than H; but in double stimuli H-C and H are slower than C and C-H.

Extreme Reactions.—The tendency to extreme reactions is very marked in double stimuli, rather more when both stimuli are perceived. In all types the tendency is greater for hot than for cold, but this is not evident in single stimuli.

Consistency.—Single stimuli give perfectly consistent responses in type, and the fluctuation, though greater than normal, is not extreme. In double stimuli, C type is quite consistent; fluctuation is high, especially for double responses.

Diminution of Sensation.—There was some general diminution of hot, more in single than in double stimuli, and of cold on the left hand.

Intensification.—The abdomen and back gave, not infrequently, slight reflexes; but they were evidently to considerable extent inhibited. The sensation was extremely disagreeable, according to patient's statement, especially cold.

Although in single stimuli cold is somewhat slower than hot; in double stimuli the hot sensation is evidently more disturbed, as is shown by the greater frequency of the cold response, and the greater delay and greater tendency to extreme reactions in hot responses, whether in double responses or alone.

The disturbance is marked and general.

MULTIPLE SCLEROSIS

The six cases studied show slight disturbances which are general in four, and local in two. Disturbance is shown chiefly by deviation from the normal type of response to double stimuli; by lengthened second intervals of double responses; and by some tendency toward diminution of sensation. Analyses of the cases follow:

CASE XII.—E. Wa. (female); age 43; housewife; intelligence good, coöperation excellent.

ONSET.—About eighteen months before test (remission for months until a year previous).

SENSATION.—Described in history, January, 1918: "Intact—pain, touch, temperature."

I. GROSS DISTURBANCE.—No failure to react. Perversion not present.

II. GENERAL CHARACTER. *Type of Response.*—The curve shows a tendency to predominance of H-C and H responses, particularly on upper part of body; the tendency is much less clear on legs, abdomen and back, and is rather strikingly reversed on the left leg.

Median Reaction-time.—In single stimuli medians are normal with slight variability, except, perhaps, on the neck and left leg for C, and abdomen for H, where there is some retardation. In double stimuli, double responses show a slight lengthening of first interval and a strikingly long second interval, the more remarkable, considering the promptness of reaction separately. C and H responses are delayed on legs and abdomen—H more than C.

Extreme Reactions.—The tendency toward extreme reactions in single stimuli, and in the first interval of double responses, is negligible; while for the second interval ninety per cent. of responses are 1.0 second or more. Single responses to double stimuli show the tendency to a small degree.

Consistency.—In single stimuli there is no inconsistency in type. The fluctuation in time, however, is rather more than normal. In double stimuli no type has a very great consistency—H being the most consistent. In time, double responses have not more than normal fluctuation in the first interval, but fluctuate markedly in the second.

Diminution of Sensation.—There is some diminution of hot, considerably more frequent in single than in double stimulation. In a considerable number of these cases, however, the initial perception of warm was followed by hot, from .8 to 4.6 seconds later. In several of these cases the interval was over 2.0 seconds, which is in itself quite unusual. No diminution of cold was reported.

Intensification.—There were no reflex retractions, although in this case, as in most multiple sclerosis cases, jerks of the legs were frequent—a random jerk, rather than an attempt to withdraw from the stimulus. Patient often reported, however, that sensation was a 'shock', which made the distinction difficult; but she asserted positively that it had no sting like very hot or very cold sensations.

Although hot tends to take precedence, except on legs and abdomen, it also shows a tendency to diminution and to an exaggeration of what may be called the crescendo effect (perception of warm followed by hot). It can hardly be said that one sensation is more disturbed than the other. What is chiefly disturbed is the immediate perception of the doubleness, regardless of which is perceived first.

The disturbance is slight and general, although it is more marked on legs and abdomen.

CASE XIII.—J. Q.; age 25; occupation not stated; intelligence and coöperation fair.

ONSET.—About three years before test.

SENSATION.—Described in history, June, 1916: O. K. Dorsal roots were cut, July,

1916. Sensory examination, October, 1916, showed analgesia; temperature anesthesia on ventral surface of leg—left more than right; and hyperesthesia to cold on dorsal aspect of thighs and lateral part of legs.

I. GROSS DISTURBANCE.—Failure to react occurred once but was insignificant. Perversion was not present.

II. GENERAL CHARACTER. *Type of Response.*—The curve is quite fluctuating for different regions. It is to be noted that H-C responses do not occur; that the abdomen has a normal percentage of C-H responses; and that, except on face and neck, C is more frequent than H.

Median Reaction-time.—In single stimuli medians are prompt, with small variability—C slightly quicker than H. In double stimuli, C responses are normal whether alone, or as first interval; while hot is delayed both in H and in C-H responses.

Extreme Reactions.—The only tendency to extreme reactions was in second interval of double responses. Most marked on legs and back; least on abdomen.

Consistency.—Single stimuli give very consistent responses both in type and time. In double stimuli, C-H and C responses each occur twice on nearly half the areas. In time, the only fluctuation of extent is in the second interval of C-H responses.

Diminution of Sensation.—Hot stimulus was regularly reported 'warm'—even with temperatures up to 47°. As patient was English-speaking, and as response 'hot' did occur, this is probably not a mere language habit. No diminution of cold was reported.

Intensification.—Reflexes occurred with cold stimuli and with double stimuli to which response was 'cold' on back. (Temperature of 47° evoked no reflex.) Jerks of legs, but not withdrawals, also occurred.

While both sensations appear to be normal in single stimulation, double stimuli show some interference with the hot in the long second interval, and in the small number of cases in which hot occurs alone, as well as in the delay of such responses.

The disturbance is slight but general.

CASE XIV.—G. P.; age 38; tailor; intelligence and coöperation fair.

ONSET.—Four years before test.

SENSATION.—Described in history, April, 1918: Normal.

I. GROSS DISTURBANCE.—No failure to react. One instance of perversion of hot occurred.

II. GENERAL CHARACTER. *Type of Response.*—Curve is practically normal—except on legs, where percentage of double responses falls and that of C rises. C is much more frequent than H.

Median Reaction-time.—In single stimuli medians are normal, with a normal amount of overlapping of C and H. In double stimuli, H-C type shows some lengthening of first interval, and of second interval on legs. Lengthening of second interval on legs is also present in C-H responses, which are otherwise normal. Single responses show some delay.

Extreme Reactions.—Extreme reactions are not very frequent and occur chiefly in second interval of double responses—more in H-C than in C-H.

Consistency.—In single stimuli consistency is normal, for both type and time. In double responses, the only abnormality in type is in the number of areas giving consistent C responses. In time the fluctuation is generally greater than normal, and is marked in the second interval of H-C responses.

Diminution of Sensation.—'Warm' was more frequent than 'hot'; and somewhat more frequent with double than with single stimuli. Occasionally, that is in three instances, the perception of warm was followed by hot—1.1, 1.5, and 2.0 seconds later. The only instance of diminution of cold occurred on the hand, where the response 'cold' followed 2.0 seconds after 'cool'.

Intensification.—There were frequent jerks of legs, but not a real withdrawal. On abdomen, however, patient sucked in his breath at the cold stimulus, and expressed surprise at its intensity.

The interference, in this case, is chiefly in the immediate perception of doubleness—whichever response came first—although when either was inhibited, it was more likely to be hot.

The disturbance is very slight, affecting chiefly the legs.

CASE XV.—J. T.; age 19; student; intelligence and coöperation good.

ONSET.—About eleven months before test.

SENSATION.—Described in history, November, 1917: O. K.

I. GROSS DISTURBANCE.—No failure to react. Perversion not present.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows H type to be most frequent, except on face, where C-H prevails; C type is very infrequent except on face.

Median Reaction-time.—In single stimuli times are normal; but are longer on legs than elsewhere. H seems to be a little quicker than C. In double

stimuli, C-H responses show a delay only in the second interval on right leg; H-C responses are prolonged in both intervals on face, legs, and abdomen—and in second interval on right arm. Single responses are slow on legs.

Extreme Reactions.—There is some tendency toward extreme reactions, which is considerable only in the case of the second interval of double responses, especially of the H-C type.

Consistency.—In single stimuli there is no inconsistency in type, but rather more than normal fluctuation in time—especially for C. In double stimuli H type has a high degree of consistency, and C-H responses are fairly consistent. The fluctuation in time is not considerable except for H-C type, although C type shows much greater fluctuation than H.

Diminution of Sensation.—There is a slight degree of diminution of both sensations, more in the case of double than of single stimuli—chiefly on legs and face for hot, and on legs and arms for cold.

Intensification.—The only suggestion of this was two reflex withdrawals on back; and one verbal report of 'very hot'.

Single stimuli show scarcely any abnormality, but suggest a slight retardation of cold and a slightly greater variability. Double stimuli confirm the view that cold is more interfered with—it is likely to be absent; if present, it is much more likely to be followed by hot than to follow it; and it shows more fluctuation and more extreme reactions than hot either as the second interval or as a single response. It is interesting to note, in this connection, the number of uncertain responses, as when patient started to enunciate 'cold' but changed his mind; or said 'cold' and then thought it was a mistake. As in case of J. Cl., hot, when perceived, very often seems to displace cold.

The disturbance is moderate and general.

CASE XVI.—I. R. (female); age 29; knitter; intelligence and coöperation good.

ONSET.—About six years before test.

SENSATION.—Dorsal roots were cut January, 1915—L II, III, V, S I. Examination in June, 1915, showed loss of sensations of touch, heat and cold over area L I and L II segments.

I. GROSS DISTURBANCE.—No failure to react. Perversions not present.

II. GENERAL CHARACTER. *Type of Response.*—Curve shows much apparent fluctuation between

C-H and H-C type (number of cases was small as patient came only once) but is evidently normal, except for a larger proportion of single responses than normal on legs and back.

Median Reaction-time.—Single stimuli give perfectly normal times except on left leg, where both C and H show some delay. Double stimuli appear slightly to increase the time of the first interval, and very slightly the second interval—and more for C-H than for H-C responses, except on right arm.

Extreme Reactions.—Practically the only extreme reactions occurred in the second interval of double responses, more often in H-C than in C-H responses.

Consistency.—No measure, as there was only one observation.

Diminution of Sensation.—While there were no reports of 'warm', and only occasionally one of 'cool', patient said that sensation on legs 'felt funny . . . only a little . . . different from rest of body'.

Intensification.—Reflexes were frequent on legs and abdomen, but the sensation was not described as intense.

What slight disturbance there is seems to be about equal for both sensations.

There is a very slight disturbance, affecting chiefly the legs.

CASE XVII.—J. B.; age 42; peddler; intelligence and coöperation good, but patient had only slight knowledge of English.

ONSET.—About seven months before test.

SENSATION.—Not noted in history, April, 1918.

I. GROSS DISTURBANCE.—No failure to react nor perversion.

II. GENERAL CHARACTER. *Type of Response.*—Reaction is quite uniformly C-H, except for single C responses on legs and back.

Median Reaction-time.—In single stimuli medians are normal; H is consistently slightly slower than C. In double stimuli the only tendency to delay is in the second interval, which is greater than 1.0 second for all regions except abdomen and back. The promptness of reaction otherwise makes this the more striking.

Extreme Reactions.—In single stimuli there were no extreme reactions; in double stimuli there were none except in the second interval where the majority were over 1.0 second.

Consistency.—No measure as patient came only once.

Diminution of Sensation.—All responses to hot stimulation were 'warm'; but whether this indicated

a real diminution of the sensation or was due to patient's slight knowledge of English, could not be determined. No diminution of cold was reported.

Intensification.—Abdomen and back occasionally gave slight reflexes with cold stimulus.

While single stimuli gave normal reaction to both cold and hot, in double stimuli hot seemed to be somewhat interfered with—being markedly delayed in double responses; never occurring alone; and showing a tendency to be inhibited altogether on legs. (In preliminary practice, it tended to be inhibited also on left arm.)

The disturbance is very slight but general.

PERIPHERAL NEURITIS

In one of the four cases studied no disturbance is shown; in one, it is shown by the number of H-C responses, and single responses, and their increased reaction-time; and in two it could not be determined whether there was any disturbance or not. Analyses of the cases follow:

CASE XVIII.—L. R.; age 17; student; intelligence and coöperation very good.

ONSET.—November, 1916, median and ulnar nerves of right arm cut by glass.

SENSATION.—Examination, January 10, 1917: Loss of touch and temperature (or deep hypesthesia) over palm and fingers, volar surfaces; and second and third phalanges of first, second and third fingers, dorsal surface. March 24, 1917: Whole palm and volar surface of fingers hypesthetic to cold—more on palm and first phalanges than on terminal phalanges. Palm normal to warm and hot. Hypesthesia to cold on dorsal surface of fingers.

PRELIMINARY TESTS.—April 27, 1918: Cold was more intense on median than on ulnar side of *right* palm—both sides being more sensitive than left palm. Second and third phalanges of first and second fingers of *right* hand were more sensitive to cold than left. Warm felt the same on both hands, but seemed a little slower in reaction on volar surface of fingers of right hand.

I. GROSS DISTURBANCE.—No failure; perversion not present.

II. GENERAL CHARACTER. *Type of Response.*—Curve is entirely normal for regions tested.

Median Reaction-time.—No difference is apparent in time of response for either arm; times are normal on those areas upon which sufficient tests were made to be reliable.

Extreme Reactions.—Rare.

Consistency.—In single stimuli consistency was normal in both type and time. In double stimuli, while consistency is normal in type, there is a slightly greater fluctuation in time. This is somewhat greater on right arm than on left—eighty-six per cent. of areas of left arm had a range under .3 second, fifty-six per cent. on right.

Diminution.—All responses to hot stimuli were 'warm'. (On right arm, temperature was 40° to 41°; on left, one series was 40° to 41°, another 45°. In one instance, sensation 'hot' followed .4 second later.) No diminution of cold was reported.

Intensification.—No evidence.

The method of the experiment shows no evidence of disturbance, although the introspective report of the patient in the preliminary tests shows that recovery is not yet quite complete.

CASE XIX.—M. F.; age 19; student; intelligence and coöperation good.

ONSET.—Median nerve of left arm cut by bullet wound, April, 1918.

SENSATION.—Described in history, May, 1918: Hypalgnesia and hypesthesia over volar surface of thumb and first and second fingers. Anesthesia over dorsal surface of first and second fingers.

PRELIMINARY TESTS.—May 18, 1918: Temperatures of 40° and 18° not felt on median surface of left hand and fingers, either dorsal or volar. Ice felt on dorsal, but not on volar median surface. Temperature of 45° felt slightly at times, on median palm and back of hand, but not on median volar surface of fingers.

I. GROSS DISTURBANCE.—Failures to react were consistent—to temperatures of 40° and 18° on dorsal and volar median surface of left hand and fingers, and to temperatures of 16° and 47° on volar median surface of fingers. No perversion occurred.

II. GENERAL CHARACTER. *Type of Response.*—Right arm shows normal distribution; left, a majority of H-C responses, and some single.

Median Reaction-time.—Tests are too few to be very reliable, but times are about normal, except for H-C responses on left arm, which are long in both intervals; single responses on left arm are also long.

Extreme Reactions.—Second interval of H-C responses gives a majority of reactions of 1.0 second or

more. Single responses to double stimuli also give some extreme reactions.

Consistency.—Cannot be measured, as patient came only once; but where two measures of a kind were obtained for any area, the range was in no case as much as 1.0 second.

Diminution of Sensation.—Some diminution of both cold and hot occurred in double stimuli—more of cold than of hot, and more on left arm than on right.

Intensification.—No evidence.

The disturbance affects the entire left arm which shows more single responses, more H-C responses, more long reactions, and more diminution of intensity than the right. The deep hypesthesia, however, is restricted, and seems to be greater for cold than for hot.

CASE XX.—H. T. (female), age 20; book-keeper; intelligence and coöperation very good.

ONSET.—Sudden paralysis of right side of face following abscess in right ear, February, 1917.

SENSATION.—Described in history, January, 1918: Normal except for loss of taste.

I. GROSS DISTURBANCE.—No failure to react. Perversion not present.

II. GENERAL CHARACTER. *Type of Response.*—The predominance of H-C responses on upper extremities and face of this patient led to a test of the legs also, where C-H were found to predominate. There were no single responses.

Median Reaction-time.—In single stimuli, medians are normally prompt, but H is consistently shorter than C. In double responses, the second interval is greater than normal, particularly in H-C responses.

Extreme Reactions.—These occurred only in second interval of double responses—in a considerable number of cases; more in H-C than in C-H type.

Consistency.—No measure, as there was only one observation, but the indications are that it would be high for the H-C type, since 47.8 per cent. of all areas which were stimulated twice with double stimuli gave two H-C responses.

Diminution of Sensation.—The only diminution occurred with hot stimuli on cheeks.

Intensification.—No evidence.

The predominance of H-C responses on upper extremities, and the long second interval, would certainly point to a disturbance of cold, if this were suspected. In the absence of any reason to suspect a disturbance, one must assume that it is an indi-

vidual difference not shown among normal subjects tested. The absence of single responses also suggests normality.

CASE XXI.—B. P. (female); age 29; housewife; intelligence rather low; coöperation good.

ONSET.—Sudden paralysis of left side of face following pain in left ear consequent on exposure to cold, February 6, 1918.

SENSATION.—Described in history, February 11, 1918: "O. K. trifacial distribution."

I. GROSS DISTURBANCE.—No failure to react. Perversion not present.

II. GENERAL CHARACTER. *Type of Response.*—Right arm and face have more single responses than normal: H on arm and C on face. Left arm has normal distribution.

Median Reaction-time.—Medians are all longer than normal, except for second interval of C-H responses.

Extreme Reactions.—These occurred to a considerable extent in first interval of C-H responses and in single H responses; none on face.

Consistency.—No measure, as patient came only once.

Diminution of Sensation.—Diminution of hot occurred in a majority of responses on all regions—slightly more with double than with single stimulus. Once the perception of hot followed after 2.2 seconds.

Intensification.—No evidence.

In the absence of more than one observation, particularly with a patient of limited intelligence, it would be rash to assert whether or not the long reaction-times, and the single responses on the right arm as well as on the face, indicated a disturbance on either region. Unfortunately, a second observation could not be obtained.

CAPSULO-THALAMIC LESION

CASE XXII.—D. L.; deaf mute; age 16; intelligence and coöperation very good in spite of his incapacity. (Patient was able to articulate sufficiently to make verbal responses though, of course, more slowly than normal.)

ONSET.—About two years before test.

SENSATION.—Described in history, October 1917: "Hypersensitivity to pain and light touch on right side of body." No mention of temperature.

I. GROSS DISTURBANCE.—There were some failures with hot stimuli on right arm and on right side of back; and with double stimuli on right arm. Perception of hot is almost complete on right side of body except on face, where perversion of cold occurred. In order to see whether patient was possibly getting paradoxical cold sensations, he was tested with temperatures of 36° to 37°. This also was called 'cold' on the right side, and 'rather hot' on left.

II. GENERAL CHARACTER. *Type of Response.*—C predominates on right side (hot not felt even alone) but C-H responses are normally frequent (or nearly so) on the left side. Single responses are rather more frequent than usual on all regions.

Median Reaction-time.—Reaction is generally longer than normal, but allowance must be made for the speech defect. They are fairly regular, however, and in H-C responses, the second interval is almost normal.

Extreme Reactions.—In spite of the generally long reaction-time there are few extreme reactions in single stimuli. In double stimuli the tendency is greater, particularly for cold in the first interval or alone, and in the second interval; oftener in C-H than in H-C.

Consistency.—In single stimuli, there is considerable inconsistency in type with hot stimuli; and fluctuation in time with both. In double stimuli, no type reaches normal consistency; but C-H and C responses occur twice with a fair degree of frequency. Fluctuation in time is fairly high.

Diminution of Sensation.—No evidence.

Intensification.—Reflexes were frequent on right side of body—even on the arm—for both sorts of stimuli and sensation was rather painful.

The disturbance of hot is profound on the entire right side of body; but allowing for the speech defect, the left side is probably about normal.

[EXPLANATION OF TABLES WILL BE FOUND ON PAGE 372]

TABLE I

In this and the following tables, the regions are numbered from I-VIII as follows: right arm, left arm, face, dorsal surface of neck, right leg, left leg, abdomen, back.

MEDIAN REACTION-TIME (IN SECONDS) FOR SEPARATE AND DOUBLE STIMULI IN SYRINGOMYELIA

Case I—P. K.

	Separate Cold Stimuli				Double Stimuli												
					Response C-H						Response Cold						
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases			
			3.0' +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0' +	2d Int. 1.0' +	Total			3.0' +	Total		
I	2.4	1.7-3.1*	1	2	1.4	.25	2.0	.75	2	6	9	2.1	1.4-2.8		2		
II	1.8	.25	1	11	2.4	.45	3.5	1.50	2	3	5	2.5	.70	2	10		
III	1.2	.00		5	1.8	.40	.5	.10		1	7	1.8	1.7-1.9		2		
IV	1.5			2													
V	1.7	.30		5													
VI	1.8	.05		5	1.4	.30	.6	.30		4	10	3.0	2.2-3.8	1	2		
VII	1.9	1.6-5.4	1	3	1.5	.25	.9	1.20	1	2	5	2.1	.35		4		
VIII	1.5	.20		5	2.2	1.8-2.6	1.6	1.20		1	2	1.8	.20		7		
Totals		-	3	38							5	20	53			3	27
Separate Hot					Response H-C						Response Hot						
I	1.6	.35		11	1.5	1.2-1.9	2.5	.8-4.2		1	2	2.1	.35		18		
II	2.0	.30		13	2.8	.50	1.9	1.50	2	4	6	2.2	.50		10		
III	1.4	.20		7	2.2	1.4-3.4	.5	.4-3.6	1	1	3	1.1	1.8-2.0		1		
IV	1.5	1.2-1.8		2													
V	1.3	.05		6													
VI	1.5	.20		6	2.2	.05	.6	.20		1	4	1.9	1.2-2.7		2		
VII	1.4	1.3-2.7		4	1.5	1.2-1.8	.4	.3-5		2	2	2.5			1		
VIII	1.8	.15		4	1.6		6.0			1	1	2.0	1.6-2.4		2		
Totals				53							3	8	18				37

* Total range is given with less than four cases.

TABLE 1. (Syringomyelia continued)

Case II—E. Wi.

	Separate Cold Stimuli				Double Stimuli										
					Response C-H							Response Cold			
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	1.2	.25		12	1.3	.20	.4	.05	I	I	24				
II	1.3	.95	2	12	1.1	.20	.5	.10			7	3.3	1.75	4	6
III	1.2	.20		6								1.0			I
IV	1.1	.9-1.3		2	1.2	.20	.4	.20		2	8				
V	1.1	.20		6	1.6	.25	.7	.80	I	6	16	1.4	1.3-1.7		3
VI	1.2	.00		5	1.3	.25	.8	.50		7	16	1.6	.25	I	8
VII	.9	.05		4	1.3	.25	.6	.20		2	12				
VIII	1.1	.10		4	1.1	.15	.4	.05			9	.9			I
Totals			2	51					2	19	92			5	19
Separate Hot					Response H-C							Response Hot			
I	1.1	.20	I	9	1.7	.25	.4	.05			7	2.1			I
II	2.0	1.00	2	7	2.5	1.6-3.4	.8	.6-1.1	I	I	2	3.7		I	I
III	1.0	.10		6								1.2			I
IV	1.0	.9-1.2		2	1.2	.10	1.1	.10		3	4	1.4	1.4-1.4		2
V	1.3	.10		6	1.7	.10	.6	.05			4	1.3			I
VI	1.3	.15		5											
VII	1.0	.05		4	1.6	1.1-2.1	1.2	.5-2.0		I	2	2.8	1.2-4.4	I	2
VIII	2.2	1.1-2.7		3	1.3	.25	.4	.05		I	6				
Totals			3	42					I	6	25			2	8

Case III—A. C.

	Separate Cold Stimuli				Double Stimuli										
					Response C-H							Response Cold			
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	3.0		I	I											
II	3.1	2.4-3.8*	I	2											
III	1.5	1.3-1.6		3								2.2			1
IV												4.6		I	I
V	3.1	2.0-4.8	2	3	2.6	2.5-2.7	3.2	1.5-5.0		2	2				
VI	1.7	1.3-4.3	I	3											
VII	3.9	3.8-4.1	2	2								2.9	1.6-4.3	I	3
VIII	3.2	2.7-3.8	I	2											
Totals			8	16						2	2			2	5
Separate Hot					Response H-C							Response Hot			
I	4.5	.90	4	4								4.8	1.35	5	6
II	4.9	2.8-5.2	2	3								7.5	6.4-8.6	2	2
III	2.6	1.4-3.0	I	3	2.2		3.6			I	I	2.0	.00		4
IV												9.6		I	I
V	2.1	1.6-2.4		3								2.6	.60	4	10
VI	2.0	1.6-2.8		3								2.2	.30	2	12
VII	4.2	2.9-5.5	I	2								4.0	.30	5	5
VIII	4.1	1.8-2.4		2								4.1	.90	3	4
Totals			8	20						I	I			22	44

* Total range given with less than four cases.

† Areas stimulated on back were shoulder blades, since usual areas did not respond at all.

TABLE I. (Syringomyelia continued)

Case IV—L. A.

	Separate Cold Stimuli				Double Stimuli												
					Response C-H						Response Cold						
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases			
			3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +	Total			3.0° +	Total		
I	1.5	.10		5	1.0	.8-1.2	.6	.5-.7			2	3.0	1.3-4.0	2	3		
II	1.7	.15	1	6	1.4	1.4-2.4	.3	.3-.5			3	1.7	1.7-2.0		3		
III	2.2	1.3-5.1	1	3	1.8	1.6-2.0	2.1	.6-3.6				2.2	2.0-2.5		2		
IV	1.7			1						1	2						
V	1.3	1.3-1.4		2	1.8	.25	.4	.05		1	7	2.9			1		
VI	2.2	1.5-2.4		3	1.9	.30	.5	.05		1	4	1.8			1		
VII	2.5	2.4-2.6		2	1.5	.10	.4	.10			5						
VIII	1.3			1	1.5	1.4-1.7	.4	.4-.4			2						
Totals				2	23							3	25			2	10
Separate Hot					Response H-C						Response Hot						
I	1.4	.40		6	1.8	.60	.8	.15		2	6	2.1	.75	1	5		
II	1.5	.05		6	1.8	.30	.5	.15	1	1	7	1.7	1.0-2.0		3		
III	1.2	1.1-1.5		3								2.0	1.1-2.9		2		
IV	1.8			1	1.6	1.5-1.7	2.6	2.6-2.7		2	2						
V	1.7	1.6-2.9		3	2.0	1.9-2.2	.6	.5-.7			2	4.0		1	1		
VI	1.6	.9-1.9		3	1.8	.10	1.3	.50		2	5	2.6	2.2-3.1	1	2		
VII	2.0	1.6-2.5		2	1.6	1.2-2.4	.4	.4-2.8		1	3						
VIII	2.1	1.4-2.8		2	1.6	.20	.4	.05			6						
Totals				26							1	8	31			3	13

Case V—J Cl.

	Separate Cold Stimuli				Double Stimuli											
					Response C-H						Response Cold					
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases		
			3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +	Total			3.0° +	Total	
I																
II																
III	1.0	.15		7	.8		1.6			1	1	1.1	1.0-1.3		2	
IV	1.2	1.0-1.2*		3								1.3	1.1-1.6		2	
V	1.2	.05		12	1.2	.05	.9	.15		3	6					
VI	1.2	.05		4	1.2	.05	.7	.45		3	8					
VII	1.7	1.6-1.8		2								1.1	.9-1.3		2	
VIII	.9	.8-1.1		2								2.2	2.1-2.3		2	
Totals				30						7	15					8
Separate Hot					Response H-C						Response Hot					
I																
II																
III	.9	.05		9	1.6		1.7			1	1	1.0	.05		8	
IV	.9	.9-.9		2								1.1	1.1-1.2		2	
V	1.1	.10		7								1.4	.10		18	
VI	1.1	.10		7								1.4	.10		16	
VII	1.0	.15		8								1.2	.20		14	
VIII	1.0	.10		9								1.2	.25		14	
Totals				42						1	1					72

* Total range given with less than four cases.

TABLE I. (Syringomyelia concluded)

Case VI—B. T.†

	Separate Cold Stimuli				Double Stimuli											
					Response C-H						Response Cold					
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases		
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total	
I																
II	4.4		1	1								2.2	1.6-2.9			3
III	2.1			1	1.7		.4				1					
IV	2.0		1	1												
V	1.7	1.5-2.0		2	1.9	.25	.4	.05		1	5					
VI	2.4		1	1	1.8	.25	.5	.00			4	2.4				1
VII	1.3		1	1	1.4	1.2-1.8	.4	.4-.4			3					
VIII	2.1		1	1	1.7	1.7-1.9	.4	.4-.5			3					
Totals			1	8							1	16				4
Separate Hot				Response H-C								Response Hot				
I	1.7	1.7-2.8		3								3.3	2.1-4.5	1		2
II	1.8			1								2.3	1.9-4.8	1		3
III	1.9	1.8-2.1		2	2.2		.5				1	1.6				1
IV	(No stimuli)															
V	2.6		1	1								3.0		1		1
VI	2.4	2.2-2.6		2	3.8		.7		1		1					
VII	1.8		1	1	2.4		.8				1					
VIII	(No stimuli)											2.4				1
Totals				10							1		3		3	8

TABLE 2

MEDIAN REACTION-TIME FOR SEPARATE AND DOUBLE STIMULI IN TABES DORSALIS

Case VII—G. C.

	Separate Cold Stimuli				Double Stimuli										
					Response C-H						Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	2.3	.35	2	13	3.4	.50	.7	.40	6	2	7	2.6	.65	3	7
II	2.3	.40	1	13	2.6	.30	.5	.15	2		13	3.0	.20	2	4
III	2.1	.20	1	6	2.8	.35	.6	.45	3	1	7	4.4	1	1	
IV	1.8	1.6-2.0*		2											
V	2.1	.30		4	3.4	2.8-3.5	.6	.6-.8	2		3	3.0	3.0-3.1	2	2
VI	2.6	.35	1	4	3.1	2.6-4.6	1.7	1.2-2.0	2	3	3	3.9	.80	3	4
VII	2.0	2.0-2.2		3											
VIII	1.6	.15		4	3.9	.25	1.0	.20	3	2	4	3.6	.25	5	5
Totals			5	49					18	8	37			16	23
Separate Hot					Response H-C						Response Hot				
I	2.0	.50	1	13	2.8	.25	.6	.15	5	2	12	2.0	.50	1	5
II	2.0	.20		13	3.1	.65	1.0	.30	6	5	18	2.9	1.4-3.7	1	3
III	1.9	.10		4	2.8	.55	.7	.15	2	2	5	1.6	1.5-1.8		2
IV	1.3	1.1-1.6		2											
V	2.5	.40	2	7	4.1	.75	2.0	1.40	4	2	4	3.6	.65	6	10
VI	3.1	.75	4	6	3.3	.25	2.1	.30	4	3	4	3.1	.30	5	9
VII	1.4	.00		4	2.4	.40	.9	.75	3	5	10	2.2	1.3-2.2		3
VIII	1.3	.05		4	2.9	.30	.7	.10	2	1	4	1.2	.9-2.0		3
Totals			7	53					26	20	57			13	35

† B. T. came only once; as the test was planned for four observations, the number is too small to make conclusions more than suggestive.

* Total range given with less than four cases.

TABLE 2. (Tabes Dorsalis continued)

Case VIII—P. O.

	Separate Cold Stimuli				Double Stimuli												
					Response C-H						Response Cold						
					1st Interval		2d Interval		No. of Cases				No. of Cases				
	Med.	P. E.	3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +			Total	Med.	P. E.	3.0° +	Total
I	1.2	.00	1	13	1.5	.50	.8	.50	1	5	11	3.0	.35	4	7		
II	1.0	.10		12	1.3	.30	2.5	.55	1	6	8	1.0	.20	1	5		
III	1.3	.30		6	1.4	.15	1.1	.55		3	5	1.1	.05		4		
IV	2.1	.8-3.4	1	2													
V	1.0	.05		6	1.7	.40	1.0	.50	2	6	12	1.4	.20	2	9		
VI	1.2	.25		6	1.6	.10	1.0	.50		3	8	1.6	.40	2	11		
VII	1.1	.40		4	1.2	.40	.5	.00			4	6.6	1.6-8.6	2	3		
VIII	.8	.5-.8		3	1.7	1.3-2.2	2.2	.6-3.8		1	2	1.7	.05	1	5		
Totals			2	52							4	24	50				

Separate Hot				Response H-C						Response Hot					
I	1.2	.00	12	1.8	.35	.5	.55	1	3	9	1.5	.25		6	
II	.9	.10	12	1.4	.45	.5	.65	1	5	12	2.4	.70	4	6	
III	1.1	.15	6	1.6	.05	1.0	.60	2	2	4	2.4			1	
IV	.6	.6-.7	2								1.3	1.2-1.4		2	
V	1.0	.05	6	1.6	1.6-1.7	.3	.3-.4			2	5.6		1	1	
VI	1.2	.10	6	2.0	2.0-2.3	.4	.4-.5	1		2	1.9	1.3-4.6	1	3	
VII	1.0	.00	4	1.6	.45	.4	.05		1	6	1.7	1.3-3.2	1	3	
VIII	.9	.05	4	2.0		.8				1	1.4	.20		9	
Totals			52							5	11	36			

Case IX—J. Co.

	Separate Cold Stimuli				Double Stimuli											
					Response C-H						Response Cold					
					1st Interval		2d Interval		No. of Cases		Med.	P. E.	No. of Cases			
	Med.	P. E.	3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+			Total	Med.	P. E.	3.0°+
I	1.0	.15		14	1.1	.05	.4	.00			5	1.5	.20		7	
II	1.0	.10		14	1.3	.10	.5	.05		I	16	.9	.9-1.0		2	
III	1.0	.15		7	1.4	.10	.6	.05		I	9					
IV	1.0	.9-1.2*	2													
V	1.1	.20		6	1.4	.15	.7	.40		3	10	1.3	.15		12	
VI	1.1	.10		6	1.2	.20	.6	.20		2	6	1.3	.20		16	
VII	1.0	.00		4	1.1	.15	.5	.15	I	I	6	6.8		I	I	
VIII	1.0	1.0-1.6		3	1.4	.25	.5	.10		I	5	1.3	1.3-1.4		2	
Totals				56						I	9	57			I	40
Separate Hot					Response H-C						Response Hot					
I	1.1	.10		12	1.3	.05	.3	.10		I	8	1.3	.10		20	
II	1.1	.10		14								1.3	.20		5	
III	1.0	.05		6	1.2	1.1-1.4	2.4	2.2-2.7		2	2	1.0	.05		4	
IV	1.0	1.0-1.0	2	2								1.4			1	
V	1.7	.75	2	7	1.6		1.0			I	I	2.7			1	
VI	1.3	.10	I	5								1.2			1	
VII	1.4	.20	I	5	1.7		.9				I	1.4	.20	I	8	
VIII	1.5	.15		4	1.5	1.4-1.6	1.0	.5-1.6		I	2	1.5	.25		8	
Totals			4	55						5	14			I	48	

* Total range given with less than four cases.

TABLE 2. (Tabes Dorsalis concluded)

Case X—L. F.

	Separate Cold Stimuli				Double Stimuli											
					Response C-H							Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases		
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total	
I	1.0	.30		9	1.2	.30	.6	.15			7	1.6	1.00	2	6	
II	1.6	.65		8	1.6	.40	.6	.10		I	5	1.7	.25		6	
III	1.0	.25		6	2.6	2.4-2.8	1.4	.4-2.5		I	2					
IV	1.0	.8-1.2		2												
V	1.4	1.3-1.7		3												
VI	1.5	1.0-1.5		3	.9	.8-1.0	.4	.4-.5			2	2.1	.00		4	
VII	1.0	.8-1.1		3	1.0	.7-1.2	.3	.3-.4			3	1.9	1.4-2.2		3	
VIII	1.9	1.8-2.1		2	1.8		.8				1					
Totals				36							2	20			2	19
Separate Hot					Response H-C							Response Hot				
I	1.4	.60	I	16	1.6	.15	.4	.05		2	11					
II	1.2	.50		10	1.4	.30	.4	.05		2	14					
III	.9	.05		6	1.1	.15	1.3	.75		6	10					
IV	1.1	.9-1.4		2												
V	2.3	1.6-3.0	I	2												
VI	1.7	.00	I	4	1.0	.40	.4	.05			12					
VII	1.1	1.0-1.1		3	.9	.05	.4	.05		I	8	1.0	.15		4	
VIII	1.1	1.1-1.2		3	.8	.25	.4	.10		I	7	.8	.05		4	
Totals			3	46							13	74				8

Case XI—H. D.

	Separate Cold Stimuli				Double Stimuli										
					Response C-H						Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	1.6	.35	1	13	1.4	.10	1.5	1.15				2.6	.50	3	9
II	1.9	.20	1	12	3.2		1.8		1	3	1	2.0	.85	4	13
III	1.6	.20		6	2.0		2.7			1	1	1.8	.20	1	7
IV	2.2	1.6-2.9*	2	3.2								1	1		
V	1.8	.20	1	6								2.1	.25	2	12
VI	2.1	.10		6	3.6	1.9-5.4	2.1	1.6-2.6	1	2	2	2.6	.35	3	13
VII	1.7	.40		5								2.4	.55	3	9
VIII	2.3	.10		4								2.8	.70	4	10
Totals			3	54					2	7	9			21	74
Separate Hot					Response H-C						Response Hot				
I	1.6	.30		12	7.3		.5		1		1	2.2	.45	2	9
II	1.7	.20		12	3.7	3.7-3.8	2.6	.5-4.8	2	1	2	3.5	1.15	4	8
III	2.3	.70		6	4.4		3.6		1	1	1	2.7	2.7-2.8		2
IV	1.6	1.3-1.9	2	5											
V	2.7	.90	2	5											
VI	2.0	.45	1	6	3.2		4.3		1	1	1	3.5	.70	3	5
VII	1.6	.25		5	4.9	3.7-6.6						2.9	2.0-3.8	2	2
VIII	1.3	.05		4											
Totals			3	52					5	3	5			15	33

* Total range given with less than four cases.

TABLE 3

MEDIAN REACTION-TIME FOR SEPARATE AND DOUBLE STIMULI IN MULTIPLE SCLEROSIS

Case XII—E. Wa.

	Separate Cold Stimuli				Double Stimuli													
					Response H-C						Response Cold							
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases				
			3.0*+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0*+	2d Int. 1.0*+	Total			3.0*+	Total			
I	1.2	.10		14	1.6													
II	1.2	.10		12	1.6	1.4-2.4	3.3	1.2-4.4		3					I			
III	1.3	.50		7	}	.15	1.2	2.20		3								
IV	1.6	1.5-1.7*		2														
V	1.2	.10		6		1.4	.20	1.4	2.50	6	7	1.5	.20			4		
VI	1.6	.20		7	1.5	.25	2.7	1.50	5	5	1.5	.25	I		12			
VII	1.3	.05		4	1.9	1.4-2.5	2.4	2.2-4.8	3	3	1.7	1.5-3.2	I		3			
VIII	1.2	.10		4	1.4	.05	1.4	.85		2	4	1.2			4			
Totals				56						22	27							
Separate Hot					Response H-C										Response Hot			
I	1.3	.10		12	1.4	.25	3.0	1.25		10	10	1.4	.20		19			
II	1.2	.10		12	1.3	.20	2.7	1.45		10	10	1.4	.20	I	17			
III	1.2	.25		6	}							1.5	.10		4			
IV	1.2	1.1-1.3		2		1.4	.25	2.4	1.25		8	8	1.3			1		
V	1.4	.15		7		1.8	1.6-2.1	5.9	4.8-7.0	2	2	2.0	.15	I		12		
VI	1.4	.25	I	6	1.6		6.1		I	I	2.6	1.00	3		6			
VII	1.7	.10		4	1.7	1.6-5.6	1.3	1.0-1.9	I	3	3	2.2	1.8-2.4		3			
VIII	1.4	.05		4	1.4	.20	2.8	1.65		5	7	1.3			1			
Totals			I	53						I	39	41						

Case XIII—J. Q.

	Separate Cold Stimuli				Double Stimuli													
					Response C-H								Response Cold					
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases				
			3.0*+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0*+	2d Int. 1.0*+	Total			3.0*+	Total			
I	.9	.10		12	}	.9	.10	.8	.45		9	19	.9	.05		8		
II	.8	.05		12		.9	.20	.8	.20		4	11	.9	.10		16		
III	.9	.10		6		.8	.05	1.6	.75		3	5	.8	.8-1.1		3		
IV	1.1	1.0-1.3		2														
V	1.3	.10		6	1.1	.00	1.5	.20	4	4	1.2	.10	14					
VI	1.2	.00		6	1.1	.10	1.6	.80	7	10	1.2	.05	10					
VII	.8	.05		4	.8	.05	.6	.30	4	14	.8	.8-.8	2					
VIII	.9	.15		4	.8	.6-1.0	3.1	2.5-3.8	2	2	.8	.00	14					
Totals				52									33	65				67
Separate Hot					Response H-C								Response Hot					
I	.9	.05		12									1.5	.20		6		
II	1.0	.05		12									1.3	.15		5		
III	.8	.05		6									1.0	.10		5		
IV	1.0	.9-1.1		2									1.4	1.0-1.5		3		
V	1.4	.20		8									1.6	.55	I	5		
VI	1.4	.40		7									2.4	2.4-2.6		3		
VII	1.2	.05		4														
VIII	1.1	.05		4														
Totals				55											I	27		

* Total range given with less than four cases.

TABLE 3. (Multiple Sclerosis continued)

Case XIV—G. P.

	Separate Cold Stimuli				Double Stimuli																
					Response C-H						Response Cold										
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases							
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total						
I	1.3	.10		14	1.4	.05	.5	.30		6	22	1.9	1.3-2.8		3						
II	1.2	.10		13	1.3	.35	.5	.10		3	20	1.7			1						
III	1.2	.00		6	1.4	.15	.4	.10	2	3	15										
IV	1.5	1.2-1.8*		2																	
V	1.6	.45		6	1.9	.50	.6	.40								3	9	1.7	.50		12
VI	1.3	.30		5	1.6	.15	1.0	.30				4	7	1.8	.20		15				
VII	1.2	1.0-2.0		3	1.4	.30	.5	.15	2	4	1.3	1.1-1.6		2							
VIII	1.3	.15		4	1.4	.15	.6	.15	4	10	1.6	1.2-1.6		3							
Totals					53							2	25	87			36				
Separate Hot				Response H-C										Response Hot							
I	1.3	.15		13	1.8	1.7-2.0	.5	.5-.6			2	2.0	.10		5						
II	1.2	.10		13	1.6	.30	.9	.60		5	11										
III	1.2	.20		7	2.1		.4				1										
IV	1.3	1.2-1.4		2	2.1	2.0-3.0	1.6	1.1-3.4	1	3	3										
V	1.4	.10		5																	
VI	1.4	.35		7	1.8	1.7-2.0	2.7	.7-4.7								1	2				
VII	1.3	.05		5															1.8		
VIII	1.5	.00		4	1.7	1.4-2.1	.5	.5-1.2		1	3										
Totals					56							1	10	22			6				

Case XV—J. T.

	Separate Cold Stimuli				Double Stimuli														
					Response C-H						Response Cold								
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases					
			3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0°	Total			3.0° +	Total				
I	1.2	.20	I	15	1.3	.35	.4	.00	I	I	8	1.3	1.2-1.8	3					
II	1.4	.20		14	1.1	.10	.4				9								
III	1.2	.25		9	1.6	.20	.6	.30			3				9				
IV	1.0	1.0-1.1		2															
V	1.6	.10		8	1.5	.10	1.2	.80		6	10				2.0	1.8-2.2	2		
VI	1.6	.05	I	8	1.6	.35	.8	.35		3	9				2.7	1.8-3.6	I	2	
VII	1.3	.00		4	1.1	.15	.5	.50		1	7								
VIII	1.0	.10		6	1.1	.05	.4	.00		I	4								
Totals			2	66							I	15	56			I	7		
Separate Hot					Response H-C								Response Hot						
I	1.0	.05	I	14	1.5	.25	2.3	.65	I	6	6	1.3	.10	3	16				
II	1.0	.10		15	1.3	.30	.6	.75		3	7	1.4	.05		14				
III	1.3	.65		7	2.1	2.0-2.3	2.1	1.0-3.2		2	2	1.8			1				
IV	1.0	1.0-1.0		3	1.8	1.0-2.6	1.5	.6-2.4		I	1	2	1.3		1.3-1.3		2		
V	1.7	.80		7									2.0		.75	3	10		
VI	1.4	.25		8	2.8	2.4-3.2	.9	.6-1.2					2		4	2.4	.40	I	10
VII	1.0	.15		4	1.9	.30	2.5	.30					3		4	1.3	.15		8
VIII	1.0	.00		4	1.3	1.2-1.4	.4	.4-.5			3	3	1.2		.25		9		
Totals			2	62							I	16	26			4	70		

* Total range given with less than four cases.

TABLE 3. (Multiple Sclerosis concluded)

Case XVI—I. R.†

	Separate Cold Stimuli				Double Stimuli										
					Response C-H						Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +	Total			3.0° +	Total
I	1.1	.05		5	1.4	1.1-1.6	.5	.4-1.5			3				
II	1.2	.05		4	1.5	.05	.9	.25		2	4				
III	1.0	.9-1.3*		3	1.9	1.2-2.2	.6	.4-1.7			3	1.6	1.6-1.6		2
IV	1.3			1											
V	1.4	1.2-1.6		3	1.5	.10	.6	.10		1	4	1.6	1.6-1.6		2
VI	2.2	1.4-2.6		3	1.9	1.1-3.7	.8	.6-.9	1		3	1.1	.9-2.4		3
VII	1.0	1.0-1.1		2	1.3	.05	.6	.10			4				
VIII	1.0			1	1.4	1.2-1.7	.9	.5-1.3		1	2	1.6			1
Totals				22					1	4	23				6
Separate Hot					Response H-C						Response Hot				
I	1.0	.05		6	1.3	.45	1.5	.85		5	7	1.3	1.2-1.4		2
II	1.2	1.1-1.3		2	1.1	.25	.5	.00		1	5	1.4			1
III	1.0	.8-1.3		3	1.6		.4				1				
IV	(No stimuli)														
V	1.6	1.4-1.8		2	2.2		.6				1				
VI	2.2	1.3-2.3		3											
VII	1.0	1.0-1.0		2											
VIII	1.0			1								1.6			1
Totals				19						6	14				4

Case XVII—J. B.†

	Separate Cold Stimuli				Double Stimuli										
					Response C-H						Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	.9	.00		6	.9	.05	1.3	.15		6	8				
II	1.0	.05		6	1.0	.15	1.3	.55		4	7				
III	.9	.8-1.2		3	1.0	1.0-1.2	1.3	1.2-4.2		3	3	1.2			1
IV	.9			1											
V	1.2	1.0-1.2		3	1.0	.00	1.3	.10		4	4	1.2			
VI	1.1	.9-1.2		3	.9	.9-1.0	1.4	1.4-1.5		2	2	1.1	.10		4
VII	.9	.9-1.0		2	1.6	1.2-1.9	.6	.6-1.6		1	3				
VIII	.9	.9-.9		2	1.2	1.1-1.3	.8	.7-.9			2	1.2			1
Totals				26						20	29				6
Separate Hot					Response H-C						Response Hot				
I	1.0	.10		6	1.2		2.8			1	1				
II	1.1	.05		6											
III	1.0	.8-1.4		3											
IV	1.6			1											
V	1.1	1.0-1.6		3	2.1		3.2			1	1				
VI	1.4	.9-1.6		3											
VII	1.0	1.0-1.0		2											
VIII	1.0	1.0-1.0		2											
Totals				26						2	2				

* Total range given with less than four cases.

† Patient came only once.

TABLE 4

MEDIAN REACTION-TIME FOR SEPARATE AND DOUBLE STIMULI IN PERIPHERAL NEURITIS

Case XVIII—L. R.

	Separate Cold Stimuli				Double Stimuli											
					Response C-H							Response Cold				
					1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases		
	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°	Total	3.0°+	Total							
I	1.2	.05		11	1.4	.25	.5	.10		2	27					
II	1.2	.20		11	1.2	.05	.4	.00			24					
III	1.1			1	1.4	.05	.4	.15		1	5					
Totals				23							3	56				
Separate Hot					Response H-C							Response Hot				
I	1.2	.05		13	1.8	.40	.6	.80		2	6	1.1			1	
II	1.2	.15		9	1.8	.40	.8	.00		1	4	2.6			1	
III	2.2			1												
Totals				23							3	10				2

Case XIX—M. F.†

	Separate Cold Stimuli				Double Stimuli										
					Response C-H						Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
			3.0°+	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0°+	2d Int. 1.0°+	Total			3.0°+	Total
I	1.6	1.2-2.0*		2	1.4	.15	.5	.05		1	5				
II	1.2	1.2-2.0		3	1.5		.4				1	4.5	2.9-6.2	1	2
Totals				5						1	6			1	2

Separate Hot				Response H-C								Response Hot			
I	1.3	1.3-1.4		2	1.4	1.3-1.6	.6	.5-.7			2				
II	1.3	1.2-1.4		2	2.0	.25	1.0	.30		6	11	1.7	1.6-4.0	1	3
Totals				4						6	13			1	3

Case XX—H. T.†

	Separate Cold Stimuli				Double Stimuli											
					Response C-H								Response Cold			
					1st Interval		2d Interval		No. of Cases							
	Med.	P. E.	No. of Cases		1st Int.	2d Int.	Total									
	Med.	P. E.	3.0°+	Total	Med.	P. E.	Med.	P. E.	3.0°+	1.0°+	Total	Med.	P. E.	3.0°+	Total	
I	1.1	.00		5	1.0	.15	.6	.05		1	4					
II	1.1	.00		4	1.0	.05	.8	.05		1	4					
III	1.1	.9-1.2		3	1.1	.10	.8	.05			4					
IV	(No stimuli)															
V	1.1			1	1.1	.05	.8	.10		1	4					
VI	(No stimuli)				1.2	.05	.8	.00		1	4					
Totals				13						4	20					
Separate Hot					Response H-C								Response Hot			
I	.8	.10		5	1.2	.15	1.0	.30		7	12					
II	.9	.00		5	1.1	.05	.8	.25		5	12					
III	.8	.8-1.0		3	1.2	.20	1.0	.30		5	7					
IV	(No stimuli)															
V	(No stimuli)				1.4	.05	1.0	.10		1	1					
VI	1.0	1.0-1.1		2												
Totals				15						18	32					

* Totals given with less than four cases.

† Patient came only once.

TABLE 4. (Peripheral Neuritis concluded)

Case XXI—B. P.†

	Separate Cold Stimuli				Double Stimuli										
					Response C-H							Response Cold			
					1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases	
					Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +	Total			3.0° +	Total
I	1.8	.10		5	2.7	.30	.4	.05	4		8	2.6			1
II	1.7	.30		5	2.4	.55	.5	.15	5	1	12				
III	1.6	1.6-2.0		3	2.8		.6				1	1.8	.10		4
Totals				13					9	1	21				5
Separate Hot					Response H-C							Response Hot			
I	1.9	.10		5	2.3		1.1			1	1	3.0	.20	3	5
II	1.6	.15		5											
III	2.1	1.5-2.6		3											
Totals				13						1	1			3	5

† Patient came only once.

TABLE 5

MEDIAN REACTION-TIME FOR SEPARATE AND DOUBLE STIMULI IN A CASE OF THALAMIC LESION

Case XXII—D. L.

	Separate Cold Stimuli				Double Stimuli											
					Response C-H							Response Cold				
	Med.	P. E.	No. of Cases		1st Interval		2d Interval		No. of Cases			Med.	P. E.	No. of Cases		
			3.0° +	Total	Med.	P. E.	Med.	P. E.	1st Int. 3.0° +	2d Int. 1.0° +	Total			3.0° +	Total	
I	2.2	.25		12	}	2.6	.40	1.2	.20	2	3	4	2.2	.35	4	30
II	2.0	.40		11												
III	2.3	.55	1	6												
IV	2.4	2.3-2.6		2												
V	2.4	.45	1	7									2.6	.35	6	24
VI	2.6	.40	2	5	2.6	.65	1.1	.30	5	14	15	2.8	.15	2	4	
VII	2.3	.10		4	2.2	1.8-2.9	1.0	.9-1.2		2	3	2.6	.25		5	
VIII	2.5	.50	2	4	2.5	1.9-3.0	1.2	1.0-2.1	1	3	3	2.8	.70	4	11	
Totals			6	51						12	36	42			17	78
Separate Hot					Response H-C							Response Hot				
I*					}	2.0	.15	.8	.15		2	9	2.0	.35		5
II	1.7	.10	1	12												
III	2.6	.25	1	5												
IV	2.0	2.0-2.0		2												
V*													2.7	.15		4
VI	2.9	.15	2	4	2.2	.30	.6	.10	1	2	8					
VII*	2.7			1	2.0	.20	.6	.30		2	7	2.2			1	
VIII*	1.7		1	3	3.2	3.0-3.5	.6	.6-.7	2		2	1.5			1	
Totals			4	25						3	8	30				11

* In response to hot stimulus:

Region I gave 10 responses Cold-Med. 2.8; P. E. .40. Region VII gave 2 responses Cold-Med. 2.7; range 2.7-3.2.
 Region V gave 6 responses Cold-Med. 3.6; P. E. .95. Region VIII gave 1 response Cold-Med. 3.8.

TABLE 6

PERVERSION OF RESPONSE—PERCENTAGE OF STIMULI GIVING OPPOSITE RESPONSE

	Syringomyelia										Tabes Dorsalis											
	P. K.		E. Wi.		A. C.		L. A.		J. Cl.		B. T.		G. C.		P. O.		J. Co.		L. F.		H. D.	
	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Hand, R	100			50	100						Right arm 100											
L					100															17		
Forearm, R	40	35			100		50													20		
L					50															17		
Arm, R	40	50			67														17			
L	40					50													67			
Face, R																			40			
L									67*													
Neck																						
Leg, R													100							50		
L													100							67		
Thigh, R							50		50*											100		
L									50*											67		
Foot, R									50*								50			33		
L				50													50	33		33		
Abdomen, R					{ 33	{ 33	{ 33	{ 63*	{ 80*										{ 50	{ 67		
L																						
Back, R															{ 25	33						
L																						

	Multiple Sclerosis										Neuritis								Thal. Les.			
	E. Wa.		J. Q.		G. P.		J. T.		I. R.		J. B.		L. R.		M. F.		H. T.		B. P.		D. L.	
	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Hand, R																						100
L																						
Forearm, R																						100
L																						
Arm, R																						50
L																						
Face, R																					33	
L																						
Neck																						
Leg, R																						100
L																						
Thigh, R																						100
L																						
Foot, R																						100
L																						
Abdomen, R																						100
L																						50
Back, R																						50
L																						

* Includes some cases in which a very dubious correction was made, from .8 to 5.0 seconds later.

Temperature Sensitivity

 TABLE 7
 FAILURE TO REACT—PERCENTAGE OF STIMULI GIVING NO RESPONSE

Syringomyelia																		
	P. K.			E. W.			A. C.			L. A.			J. Cl.			B. T.		
	C	H	D	C	H	D	C	H	D	C	H	D	C	H	D	C	H	D
Hand, R							88		75				100	100	100	{ Right arm— C & H—17%	38	
L				100	100	94	88	80	88				100	100	100			
Forearm, R								67	100				100	100	100			
L						13	50	100	100				100	100	100	{ Left arm— C & H—67%	63	
Arm, R								67					100	100	100			
L							75	40	75				100	100	100			
Face, { R																		
{ M																		
L																		
Neck							100	100										100
Leg, R																		
L																		
Thigh, R																		
L																		
Foot, R																		
L												25						
Abdomen, R												25						
M							{ 25	{ 25										
L																		
Back, R							{ 100	{ 100	{ 100*									
M																		
L																		

Multiple Sclerosis																		
	E. Wa.			J. Q.			G. P.			J. T.			I. R.			J. B.		
	C	H	D	C	H	D	C	H	D	C	H	D	C	H	D	C	H	D
Hand, R																		
L																		
Forearm, R																		
L																		
Arm, R																		
L																		
Face, R																		
L																		
Neck																		
Leg, R																		
L																		
Thigh, R																		
L																		
Foot, R																		
L																		
Abdomen																		
Back																		
R																		
M																		
L																		

C indicates cold stimuli; H, hot; and D, double stimuli.

* Areas usually stimulated gave no response; responses were obtained on shoulder blades.

TABLE 7. (concluded)

Tabes Dorsalis														
G. C.			P. O.			J. Co.			L. F.			H. D.		
C	H	D	C	H	D	C	H	D	C	H	D	C	H	D
								25						
							67							

Neuritis												Thalamic Lesion		
L. R.			M. F.			H. T.			B. P.			D. L.		
C	H	D	C	H	D	C	H	D	C	H	D	C	H	D
			33	33	14†								50	25
													50	

These percentages were with temperatures of 16-17° and 46-50° C.; temperatures of 18° and 40° evoked no response on the median face of the left hand.

Temperature Sensitivity

 TABLE 9
 DIMINUTION OF SENSATION—PER CENT. OF WARM RESPONSES

Region	Syringomyelia												Tabes Dorsalis									
	P. K.		E. Wl.		A. C.		L. A.		J. Cl.		B. T.		G. C.		P. O.		J. Co.		L. F.		H. D.	
	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
I	97	64	94	58	67	50	100	100			100	100	38	31			32	17			71	
II	76	92	70	28	100	67	100	100			100	100	12	23			50	47			18	
III	67	71	91	50	40	33	100	100			100	100	20				25					
IV	100	100	50	50			100	100			100	100					75	50				
V	83	67	81	83	8		100	100			100	100	18	44			75	86			60	4
VI	94	83	100	50		33	100	100			100	100	38	33			57	71			60	5
VII	38	50	88	100	60	25	100	100			100	100					33					2
VIII	100	75	53	50	25		100	100			100	100	27				29					

DIMINUTION OF SENSATION—PER CENT. OF COOL RESPONSES

	Syringomyelia												Tabes Dorsalis									
	P. K.		E. Wl.		A. C.		L. A.		J. Cl.		B. T.		G. C.		P. O.		J. Co.		L. F.		H. D.	
	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
I	7												25	14								
II	10	14											14								13	
III					50								16									
IV													50									
V													50									
VI													27									
VII													14									
VIII																						

 TABLE 10
 INTENSIFICATION OF SENSATION

	Syringomyelia												Tabes Dorsalis											
	P. K.		E. Wi.		A. C.		L. A.		J. Cl.		B. T.		G. C.		P. O.		J. Co.		L. F.		H. D.			
	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S		
I																								
II																				1C*				
III																			1HC					
IV																								
V					1H									1C	1CH	1C				1C*				
VI					2H	1C									2C	1HC			1HC	1C				
VII														1HC	2CH				4HC	6C†	1CH	20		
														1H	1HC				4H	5H†	1C	21		
															3H&									
															3C									
VIII														2H	1C		1C*	2H	1C	4HC	6C†	1H		
																3H	1C	1H	5H	5H†				

Under D is shown the number of cases of reflex retraction from a double stimulus, with initials indicating the type of response; under S reflexes occurring with single stimuli—initials indicating which.

Multiple Sclerosis												Neuritis								Thalamic Lesion	
E. Wa.		J. Q.		G. P.		J. T.		I. R.		J. B.		L. R.		M. F.		H. T.		B. P.		D. L.	
D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
25	92	100	100	93	92	6				100	100	100	100	14				77	40		
6	42	100	100		90	85				100	100	100	100	19				78	80		
30	50	100	100	92	100	30	43			100	100	100	100			11	33	50	100		
25	8	100	100	100	50					100	100										
65	100	100	85	100	100	23				100	100										
58	100	100	100	100	85	23				100	100										
44		100	100	93	100	5				100	100										
15	20	100	100	92	50					100	100										

Multiple Sclerosis												Neuritis								Thalamic Lesion	
E. Wa.		J. Q.		G. P.		J. T.		I. R.		J. B.		L. R.		M. F.		H. T.		B. P.		D. L.	
D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
					7		7								14						
						6		11							60						
							7														
						8				33											

Under D is to be found the per cent. of responses to double stimuli including any perception of the hot stimulus, which were warm; under S the per cent. of warm responses to single hot stimuli.

Multiple Sclerosis												Neuritis								Thalamic Lesion	
E. Wa.		J. Q.		G. P.		J. T.		I. R.		J. B.		L. R.		M. F.		H. T.		B. P.		D. L.	
D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S	D	S
																				1C	2C
								1CH												6C	1C&1H
								2C													
								1C													
								4CH		1C											1C
		4C	1C			1H	1C			1C										1C	1C&1H

* Response was H-C or H.

† 3 responses were H-C, 1 H.

‡ 3 responses were H-C.

‡ 2 responses were H-C.

TABLE 8
CONSISTENCY OF RESPONSE

Single Stimuli	Syringomyelia			Tabes Dorsalis				Multiple Sclerosis				Neuritis Thalamic Lesion		
	P. K.	E. W.	J. C.	G. C.	P. O.	J. C.	L. F.	H. D.	E. W.	J. Q.	G. P.	J. T.	L. R.	D. L.
Per cent. of areas having														
Cold—2 C responses	56	92	44	73	96	96	46	100	100	100	89	100	90	92
Hot—2 H responses	84	73	100	50	92	96	69	100	100	100	96	100	100	44
Cold—range 1.0"	14	17		16	24		17	23	23		8	23		20
Hot—range 1.0"	10	11	6	10	4	8	28	20	12		4	19		27
Cold—range <.3"	29	47	19		32	60	33	35	65	77	50	12	56	24
Hot—range <.3"	33	50	69	35	64	52	28	24	42	73	52	69	75	36
Double Stimuli														
Per cent. of areas having														
2 or more responses—C-H	40	48	17	28	38	45	8	3	20	48	75	43	89	35
2 or more responses—H-C	8	18		33	20	5	70		25		10	13	16	20
2 or more responses—C	18	13	8	18	33	28	15	65	15	48	23	6		48
2 or more responses—H	25	3	96	25	35	8	20	45	23			75		5
C-H, 1st—range 1.0"	19	35	0	27	54	6	33	100	0	0	23	29	25	50
2nd—range 1.0"	25	21	25	27	33	28	0	100	63	42	40	24	0	35
C-H, 1st—range <.3"	25	24	100	91	7	67	33	0	50	58	23	47	25	0
2nd—range <.3"	38	35	50	27	27	39	67	0	13	16	30	53	70	21
H-C, 1st—range 1.0"	33	29		65	38	0	25		10		0	40	0	13
2nd—range 1.0"	67	29		38	50	50	18		90		75	60	67	38
H-C, 1st—range <.3"	0	43		8	38	50	22		40		0	40	33	38
2nd—range <.3"	33	43		23	50	50	68		0		0	0	33	0
C—range 1.0"	28	60	0	57	46	0	0	54	33	0	44	50		63
C—range <.3"	29	0	0	14	15	46	17	8	17	68	11	0		0
H—range 1.0"	40	0	0	40	44	21	0	50	28	13		7		100
H—range <.3"	10	100	22	50	22	29	50	13	39	50		43		0

The percentage of areas having two responses of a kind is calculated on the basis of all areas stimulated—forty for double stimuli, twenty-six for single stimuli (except in cases where for some reason an area failed to receive two stimulations).*

The percentage of areas having a given range is calculated on the basis of the number of areas giving two responses of the sort indicated.

Figures in italics indicate percentages outside of normal limits—i. e., deviating from the normal average by more than two and a half times the average deviation. But C or H responses among normals were so infrequent that the time-fluctuation was not calculated.

* For single stimuli, two responses of a kind indicates 100 per cent. for that area, in general; for double stimuli, 50 per cent.

[OWING TO EXIGENCIES OF MAKE-UP, TABLES 9 AND 10 WILL BE FOUND ON PAGES 362 AND 363]

TABLE 11

COMPARISON OF THE REACTION-TIME OF COLD AND HOT IN SINGLE STIMULI

Syringomyelia						Multiple Sclerosis					
	Time of C > H		Time of H > C		Time of C = H		Time of C > H		Time of H > C		Time of C = H
	No. of Regions	Average Amount Sec.	No. of Regions	Average Amount Sec.	No. of Regions		No. of Regions	Average Amount Sec.	No. of Regions	Average Amount Sec.	No. of Regions
P. K.	4	.50	3	.23	1	E. Wa.	3	.23	4	.20	1
E. Wi.	3	.13	5	.44		J. Q.	2	.10	5	.22	1
A. C.	2	1.05	5	1.00	1	G. P.	2	.20	3	.13	3
L. A.	5	.48	3	.40		J. T.	4	.28	2	.10	2
J. Cl.	5	.24	1	.10	2	I. R.	3	.05	1	.20	4
B. T.	2	1.90	2	.70	1	J. B.	1	.10	7	.21	
Average	3.8	.48	3.4	.43		Average	2.8	.17	3	.17	
Tabes Dorsalis						Neuritis					
G. C.	6	.37	2	.45		L. R.			1	1.10	2
P. O.	4	.48	1	.10	3	M. F.	1	.30	1	.10	
J. Co.			6	.32	2	H. T.	4	.23			
L. F.	3	.40	5	.30		B. P.	1	.10	2	.30	
H. D.	5	.40	2	.80	1	Average	1.5	.16	1	.37	
Average	3.6	.34	3.2	.39							
Thalamic Lesion											
D. L.	3	.50	3	.40							

TABLE 12

COMPARISON OF THE REACTION-TIME OF COLD AND OF HOT RESPECTIVELY IN SINGLE AND DOUBLE STIMULI

	C & C-H	H & H-C		C & C-H	H & H-C		C & C-H	H & H-C		C & C-H	H & H-C
P. K.	+ .1	+2.1	G. C.	+6.3	+7.4	E. Wa.	+1.7	+1.0	L. R.	+ .5	+1.2
E. Wi.	+ .8	+1.4	P. O.	+2.6	+4.8	J. Q.	- .4		M. F.	+ .1	+ .8
A. C.			J. Co.	+1.6	+ .6	G. P.	+1.3	+3.1	H. T.	- .2	+1.0
L. A.	-1.8	+ .1	L. F.	+ .7	-1.8	J. T.	0	+4.3	B. P.	+2.8	
J. Cl.	- .2		H. D.	+ .4*	+2.7	I. R.	+1.9	+ .8			
B. T.	- .5*	+ .9*				J. B.	+ .7		D. L.	+ .8	+ .4
Av.	- .3	+1.1		+2.3	+2.7		+ .9	+2.3	(Neur.)	+ .8	+1.3

These figures represent the sum of the gains in time of medians (in seconds) for each individual in double stimuli over medians in single for same region. Starred figures, however, are gains of averages, so calculated because of too few cases to calculate by regions.

CHART A

SUMMARY OF DISTURBANCE IN ALL CASES

	Syringomyelia						Tabes Dorsalis				
	P. K.	E. W.	A. C.	L. A.	J. Cl.	B. T.	G. C.	P. O.	J. Co.	L. F.	H. D.
Failure to react		+	++++	+	+++++	++			+		
Perversion	++	+	++++	++	++++	+++++	++++	+	++	++++	
Type of response	++	+	+++++	++++	+++++	++	+++++	+++++	++	++	+++++
Median reaction-time	+++	++	++++	++	+	++	++	+	+	+	++++
Extreme reactions	+++	+++	+++++	+++	++	++	+++++	+++	+	+	+++++
Consistency	+++++	+++	No meas.	No meas.	++	No meas.	+++++	+++	++	+++	++++
Diminution of sensation	+++++	+++++	++	+++++		+++++	+++		++	++	++
Intensification	+		+				+		+	+	++
Relatively greater disturbance	C ₅ H _d	H	C	C	C	C	C	C ₅ H _d	H	C	C ₅ H _d
Degree of disturbance	++	++	+++++	++	+++++	+++++	+++	++	+	+	++++
Disturbance general	+		+	+			+	+	+	+	+
Disturbance local		+			+	+					

	Multiple Sclerosis						Neuritis				Thalamic Lesion
	E. Wa.	J. Q.	G. P.	J. T.	I. R.	J. B.	L. R.	M. F.	H. T.	B. P.	D. L.
Failure to react		+						+			+
Perversion			+								+++++
Type of response	+++++	+++++	+	+++	+	+		+	+	+	++
Median reaction-time	+	+	+	+	+	+		++	+	++	++
Extreme reactions	++	++	+	++	+	++		++++	++	++++	+++++
Consistency	+++	++	+	++	No meas.	No meas.	+	No meas.	No meas.	No meas.	+++++
Diminution of sensation	++	+++++	+++++	+		+++++	+++++	+	+	+++++	
Intensification		+	+	+	+	+					++
Relatively greater disturbance	C = H	H	H	C	C = H	H	-	C	C?	?	H
Degree of disturbance	+	+	+	++	+	+	-	+++	?	?	+++++
Disturbance general	+	+		+		+			?	?	
Disturbance local			+		+			+			+

In each aspect of the experiment, as designated on the left, the relative degree of disturbance is indicated for each subject by the number of plus signs—except in the last two, where the sign signifies whether the disturbance was general or local in character.

That there is in most of these cases a departure from the normal reaction is evident; and that the double stimulation shows a disturbance not always evident with separate stimuli is also clear. Perhaps the nature of the disturbance will be more quickly grasped by the summary in Chart A, in which the estimated degree of disturbance shown by each subject in the various aspects of the test is indicated by plus signs.

The chart is also a convenient reference table for comparing the various syndromes. There are a few salient points to be noted:

1. Failures are by far the most frequent in syringomyelia.

2. Perversions are commonest in syringomyelia; but are frequent also in tabes,* and in the case of thalamic lesion.

3. In type of response neuritis deviates least from normal—but these cases for the most part showed no clear-cut disturbance. Other syndromes do not differ significantly in this respect one from another.

4. In reaction-time multiple sclerosis is nearest to normal. If reference is made to Tables 1-5 it will be seen that these cases are generally prompt in reaction to separate stimuli; and that they generally show a retardation, chiefly in the second interval of double responses.

5. Extreme reactions in the second interval of double responses only are characteristic of multiple sclerosis. Except in multiple sclerosis extreme reactions are also frequent in single responses to double stimuli.

6. Diminution of intensity of sensation is least and intensification is most in tabes dorsalis.

7. Cold is more likely to show a greater disturbance than hot in syringomyelia; hot more than cold in multiple sclerosis.

8. All factors considered, multiple sclerosis shows the least degree of disturbance.

9. The disturbance is unlikely to be local in tabes, most likely to be local in syringomyelia.

Summarizing, one may say that under the conditions of the experiment—for these subjects at least—frequency of failures and of perversions, generally lengthened reaction-times, diminution of sensation, and tendencies toward marked local disturbance are indicative of syringomyelia. Perversions without failures; somewhat lengthened reaction-time—especially in double stimuli; tendencies toward intensification; and gen-

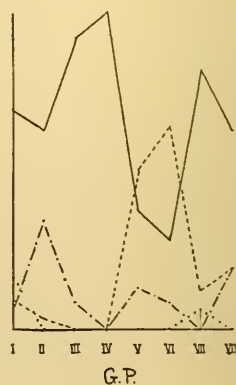
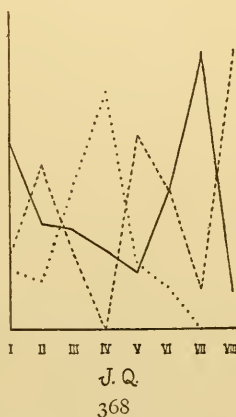
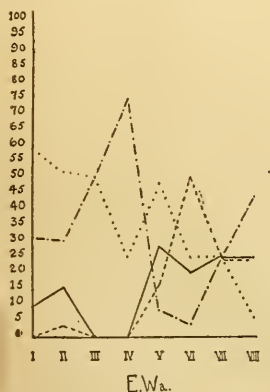
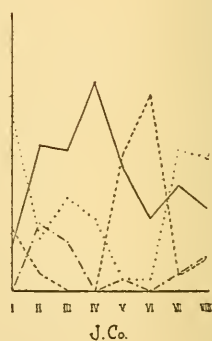
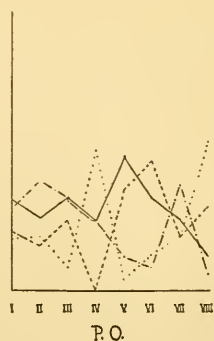
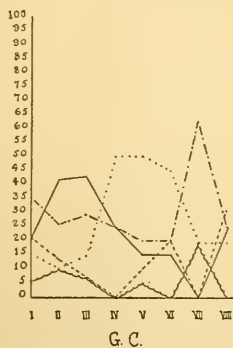
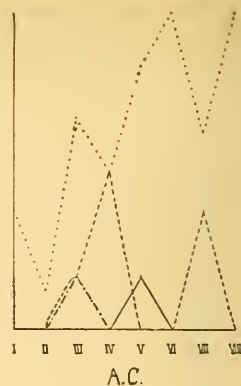
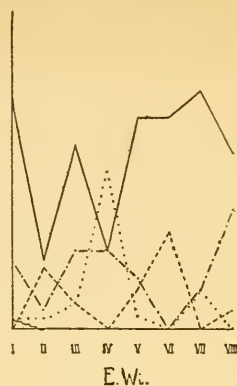
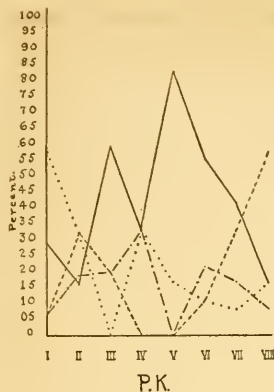
eral, rather than local, character of disturbance suggest tabes. A generally normal or nearly normal reaction—except for a lengthened interval between the perception of the two stimuli—is characteristic of multiple sclerosis. The lesion of the brain stem is distinguished from those of the cord by the unilateral character of the disturbance, and by the clear-cut selection of one sort of sensation as evidenced by the responses. Peripheral disturbances, such as traumatic neuritis, are not adequately shown by this method of testing.

There are a few points which may be of general interest to the theory of temperature sensations. One is the relation of the order of response in double stimuli to the length of reaction of cold and hot separately. It will be remembered that with *normals*, while the time for cold and hot was about the same, the majority of responses to the double stimulus were in the order *cold-hot* and that these responses were slightly more prompt and less variable, in both intervals, than those in the order *hot-cold*; ⁷ that the responses of hot followed quite regularly upon those of cold except on legs and feet, where it was somewhat delayed. In testing *abnormals* we have an opportunity to see what happens when the times of hot and cold are more variable.

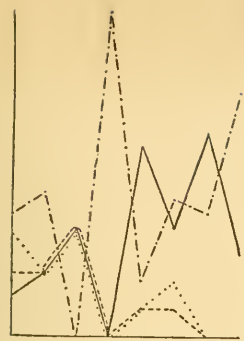
Table 11 gives a summary of the relation of cold and hot on each region, for the various subjects. We find, that in spite of greater variability there is, generally considered, the same overlapping in the times of cold and hot that was found among normals. There are four subjects, however, in whom is shown a fairly distinct tendency of hot to be slower—E. Wi., J. Co., J. Q. and J. B.; and there are six who show a somewhat slower time for cold—P. K., J. Cl., G. C., P. O., H. D. and J. T. Of the cases in whom cold is quicker, we find, by comparing the frequency of different types of response to double stimuli (Tables 1-5), that C-H responses exceed H-C in all cases, and C exceed H in all but one case; that C-H is the most frequent type in all but one case, in whom C has the highest frequency. On the other hand, among those

⁷Neurological Bulletin, loc. cit., Table 12, p. 156

Temperature Sensitivity



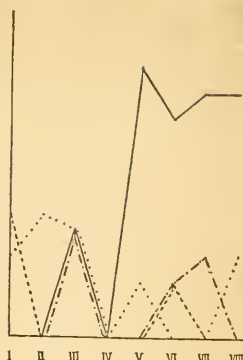
Temperature Sensitivity



L.A.



J.Cl.



B.T.



L.F.



H.D.

FIG. 1. (TOP) DISTRIBUTION OF TYPES OF RESPONSE IN SYRINGOMYELIA

— C-H — H-C --- C H ~~~~~ Doubtful

FIG. 2. (CENTRE) DISTRIBUTION OF TYPES OF RESPONSE IN TABES DORSALIS

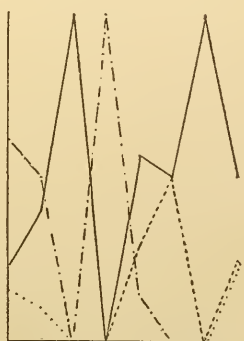
— C-H — H-C --- C H ~~~~~ Doubtful

FIG. 3. (LOWER) DISTRIBUTION OF RESPONSE IN MULTIPLE SCLEROSIS

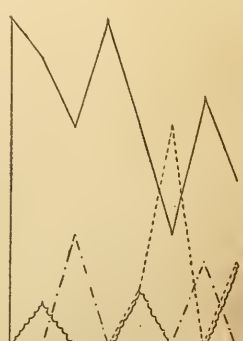
— C-H — H-C --- C H ~~~~~ Doubtful



J.T.



I.R.



J.B.

Temperature Sensitivity

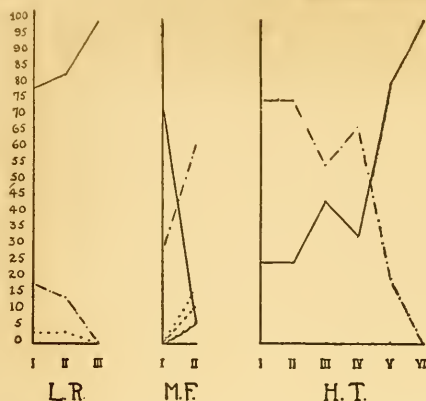


FIG. 4. DISTRIBUTION OF TYPES OF RESPONSE IN PERIPHERAL NEURITIS
— C-H — H-C — C H — Doubtful

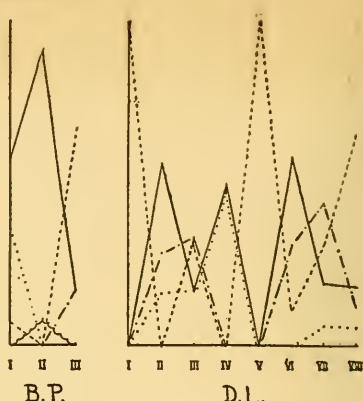


FIG. 5. DISTRIBUTION OF TYPES OF RESPONSE IN A CAPSULOTHALAMIC LESION

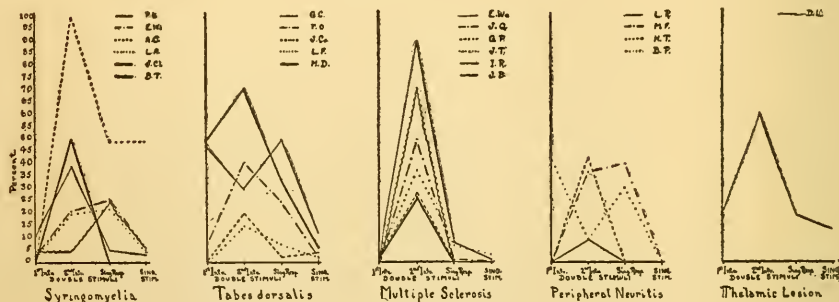


FIG. 6. EXTREME REACTIONS

A graph showing manner in which extreme reactions were distributed among the different types of response

who show a slightly slower reaction to cold, H-C responses exceed C-H in only one case, though H are more frequent than C in four cases; and the most frequent type in three cases is C-H or C, although in three others, it is H or H-C. Thus, the frequency of the type of response does not invariably depend on the length of the reaction to separate stimuli. Indeed, as results show, the entire character of the disturbance may be greater for hot in double stimuli, in spite of a slower cold reaction. The opposite, however, does not occur.

Another point of interest is the effect of double stimulation upon the length of reaction-time. If the gains in the medians for

the double stimulus over the single, for each region, are added algebraically, for each subject, we get a rough measure of the effect of the double stimulus. This is shown in Table 12. The same sort of measure for normals can be easily computed from Table 12 of the former article. It will show that while the reaction to cold remained practically the same in C-H responses as in single stimuli (sum of the gains, total, equals -1 second), the reaction to H in H-C responses was somewhat lengthened (sum of gains, $+2.9$ seconds).

The tendency of the clinical subjects is in general to increase the time for either response in double stimuli. The increase is greater for hot than for cold in twelve cases, and less in

five—the remaining five patients having too few H-C responses to admit of comparison. The five cases showing less increase for hot than for cold are not, however, of those who react more slowly to cold. There are four cases that show a decrease in time of cold in double stimuli; in only one, however, is the difference very considerable. There is but one case showing a decrease in time of hot; this is the subject who reacted to almost all stimuli—single and double—by H-C. The tendency is, then—as in normals—for double stimuli to increase the reaction-time of hot more than of cold.

This leads us to the third point of general interest: that the C-H type of response indicates the least abnormality of response. It was noted even among normals that H-C responses were more irregular when they occurred than C-H, but it was assumed that this was because of the fewer number of cases of this type. Among the subjects of the present inquiry the same phenomenon appears. A slighter degree of disturbance for C-H than for H-C responses is shown by every subject—whether cold or hot is more disturbed—in the time of either first or second interval, or the proportion of extreme reactions, or in all three ways—except in the case of D. L., in whom H-C responses, although less frequent, are shorter in both intervals and less apt to be extreme. Single responses to double stimuli, are in general, longer and more apt to be extreme than double responses; that is, they indicate the greatest divergence from the normal, except in multiple sclerosis, where the only significant divergence is the lengthening of the second interval.

Here it may be observed that this seems to imply that the process of dissociation in multiple sclerosis is of a different character from that in syringomyelia or tabes in that, instead of retarding the initial perception when the double stimulus is given, the tendency is to lengthen, if not to inhibit, the perception of the second. Whereas in tabes, the prolongation of the initial perception is quite marked (*cf.* Table 12). In syringomyelia, however, the reaction is slow even for separate stimuli, and the curious result is that in three subjects, C-H responses are

quicker than responses to cold separately—another proof of the slighter disturbance indicated by the C-H type of response. It may be that this retardation of the perception of the second stimulus is dependent on the degree of disturbance rather than characteristic of a particular syndrome: H. T., a neuritis case with scarcely any disturbance, and J. Cl., a syringomyelia case in whom the disturbance is quite limited, show the same general tendency. Nevertheless, since other subjects in whom the disturbance is slight do not show it, and since all the cases of multiple sclerosis tested—even those in whom the dorsal nerve roots had been severed—do show it, it seems fair to regard it as characteristic of multiple sclerosis.

To return to the points of theoretical interest. The three tendencies mentioned—that, even when cold is separately more delayed, hot is less apt to predominate in double stimuli; that in general, the perception of hot in double stimuli is more increased in time than cold, and that the exceptions to this are not the cases in which cold is separately slower; that C-H responses are nearest to normal whichever sensation is more disturbed—suggest that the double stimulation acts in a way which is not merely the additive effect of the two stimuli, but which indicates some relation between the two tending to delay the perception of hot.

The theory that best explains these facts, is, in my opinion, that which regards the perception of hot as a fusion of impulses from cold and warm spots. On this hypothesis, the double stimulation requires the cold spots to do double duty, so to speak, and naturally the fulfilment of their secondary function is delayed. This hypothesis also explains most easily the cases of perversion—at least those which do not occur with complete consistency. If cold takes part in the perception of hot, then it is not difficult to imagine the fusion disturbed and cold perceived as hot or *vice versa*. The tendencies are, however, not sufficiently unequivocal to make this interpretation of more than doubtful correctness—and there are two cases whose reaction is difficult, though not impossible, to explain on this assumption. These are J. Cl. and J. T.,

who show a normal reaction to cold and hot separately, somewhat quicker, however, for hot, but a considerable interference with the reaction to cold in double stimuli. It is difficult to see how the reaction to hot can remain intact, on our hypothesis, when cold is disturbed. It is necessary to assume that the cold, in exercising its second function, loses its identity in its first function because the second reaction comes so quickly. The number of instances for which both of these subjects started to say "cold" but said "hot" instead, makes this explanation not improbable.

CONCLUSIONS

1. Patients suffering from syringomyelia, tabes dorsalis, multiple sclerosis, and the type of thalamic lesion presented in this study, generally show some disturbance in reactions to double thermal stimuli, whether or not evinced by ordinary clinical tests. The temperature test, as herein presented, is not, however, well adapted to the investigation of peripheral disturbances.

2. There is a larger proportion than normal of single responses to double stimuli.

3. There is more than a normal tendency, in many cases, to call temperatures of 41° to 44°C. or higher, *warm* instead of the usual hot.

4. The disturbance is generally shown by an increased reaction-time.

5. The variability in time is greater than normal: the range of medians for different regions being greater and the consistency of single areas less.

6. Reactions to double stimuli are in general more disturbed than reactions to single; and H-C responses more than C-H.

7. C-H responses indicate the nearest approach to the normal reaction; they are the most frequent type in the least disturbed cases (with one exception); and they are nearest to normal in time for each individual.

8. The type of response to double stimuli, and the character of disturbance, cannot be predicted from the response to single stimuli.

9. The differences between the different syndromes are sufficiently distinct to be suggestive, although there is some overlapping. Multiple sclerosis has a particularly clear-cut characteristic—a dissociation of the perception of *doubleness*.

10. The double stimulation acts in such a way as to delay the perception of hot more often than that of cold.

EXPLANATION OF TABLES

Tables 1-5 show the median reaction-times of each patient in the five syndromes studied, both for separate and double stimuli, and for each type of response; the P. E., the number of extreme reactions, and the total number of responses for each region.

Tables 6 and 7 present the evidences of gross disturbance—the percentages of stimuli that gave failures and perverted responses.

Table 8 gives the percentages of consistency in type of response and in time, as is explained above. A glance at the italicized figures shows that the inconsistency was considerable among these subjects.

Table 9 shows the percentages of responses that were *warm* and *cool*, instead of *hot* and *cold*, in both separate and double stimuli. This is quite striking in view of the fact that seven per cent. of the total was the highest percentage reached by normals.

Table 10 gives the number of cases for each region of each subject in which an intensification of the sensation might be assumed by the reflex accompaniment. This is of interest in comparing the different subjects and syndromes, although no standard can be offered for reference.

Table 11 presents a comparison of the time of cold and hot responses in single stimuli. It gives for each subject the number of regions on which *cold* gave a longer time than *hot* with the average difference in time; the number of regions and the average time difference where *hot* was longer than cold; and the number of regions on which the time for cold and hot was the same.

Table 12 is a comparison of reaction-times of cold in single and double stimuli and similarly of hot.

Figures 1-5 present graphically the manner in which responses to double stimuli were distributed among the different types of response.

Figure 6. Figure 6 is a graph showing the distribution of extreme reactions among the different types of response in the various syndromes.

VITA

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